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Irrigation in U.S. Agriculture: On-Farm Technologies and Best Management Practices

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Summary

Recent threats to water availability as a result of moderate to exceptional drought in several states have raised questions about agricultural water use and efficiencies across the United States. An understanding of common irrigation technologies and the impacts of best management practices in irrigation may be useful to Congress concerning potential policy responses to this issue. As a major user of water, the agricultural industry's use of water resources continues to be a focal point of agriculture policy. Additional demands on water supplies, extreme weather events (e.g., prolonged drought), and agricultural market conditions have raised producers' interest in investing in irrigation systems. Increased pressure on the industry to reduce its water use has also drawn interest in the adoption of irrigation technologies and best management practices (BMPs) as a means of achieving efficiency and potential water savings.

The federal government performs several roles in assisting agricultural producers with irrigation practices, including financial assistance, technical assistance, research, and monitoring and reporting. The majority of financial and technical assistance is offered through voluntary conservation programs that target increased irrigation efficiency. In some cases, improvements in irrigation efficiency can increase water consumption because farmers increase the number of irrigated acres or grow more profitable, water-intensive crops. This raises questions about how and where federal funds are allocated, particularly in areas where water shortages are a concern.

The use and significance of irrigated agriculture varies widely across the United States. Although policy discussions related to irrigation typically focus on western states—home to roughly 71% of irrigated farms—irrigation is practiced in all 50 states and is growing in the east. Over time, there has been a shift in water resources used for irrigation, with an increasing reliance on groundwater and less on the use of surface water.

The type of irrigation system used has also shifted over time—from a gravity, or flood-type of irrigation, to potentially more efficient pressurized sprinkler and drip irrigation systems. Pressure systems account for between 58 to 65% of irrigation systems used in the United States and include applicators such as center pivot, surface drip, slide roll or wheel move, and micro sprinkler. Gravity flow, which includes furrow, and controlled and uncontrolled flooding, accounts for approximately 35 to 42% of irrigation systems in the United States. Irrigation BMPs center around how water is managed on a farm and includes on-farm conveyance, irrigation scheduling, and application methods. Increasingly, precision technologies (e.g., drones, sensor networks, data analytics, etc.) are becoming a common part of many irrigation systems because of their potential to increase efficiencies and reduce costs.

The use of irrigation technology and BMPs bring both benefits and costs. The control of water application achieved through irrigation systems can create higher yields and allow the production of higher value crops, while potentially reducing some production costs. The additional cost of installing and maintaining these systems, however, can present a barrier to implementing BMPs. Accounting for variations in the local climate, soil type, water quality, and water availability may also challenge adoption of irrigation technologies and BMPs.

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Agriculture is a major user of water in the United States. How the industry utilizes water resources through irrigation technologies and best management practices continues to be a focal point of agriculture policy. Recent droughts and water shortages have resulted in agricultural producers and conveyance institutions rethinking how water is delivered to and used on the farm to adjust to water shortages.[1] Drought and water shortages affecting farmers' ability to irrigate, however, are not isolated to the western United States. Between 2008 and 2013, irrigation was discontinued on over 470,000 acres of farmland across the United States due to surface and groundwater shortages.[2] Given the increasing demands on water supplies for other users and uses, especially for the urbanizing West, there are pressures for the agricultural industry to reduce its water footprint. At the same time, there are other forces (e.g., markets, policies, and droughts) that are encouraging increased interest in irrigation adoption and efficiency.

Irrigation, generally defined, is the artificial application of water to plants to sustain or enhance plant growth. There are three primary sources of water for on-farm irrigation: groundwater from wells (55% of irrigation water applied in 2013), water delivered to farms (35%), and on-farm surface water (10%).[3]

The use and significance of irrigated agriculture varies widely across the United States. Five states (Nebraska, California, Arkansas, Texas, and Idaho) alone represent 52% of the total irrigated acres nationally.[4] As shown in **Figure 1**, irrigated farms in several western states (Arizona, California, Idaho, Nevada, New Mexico, Utah, and Wyoming) and two eastern states (Arkansas and Florida) produce over 89% of the market value of crops sold in those states. In 2012, farms with irrigated land accounted for 50% ($106.3 billion) of the market value of crops sold in the United States, with roughly 71% of irrigated farms residing in the 17 western states.[5] Although the market share of many western states is high, most have seen a reduction in irrigated acres since 1997 (see **Figure 2**). At the same time, irrigation in the east is growing, with some states seeing a percent increase of more than 50% over this same time period.

[1] U.S. Department of the Interior, Bureau of Reclamation, "Chapter 4: Agricultural Water Conservation, Productivity, and Transfers," *Colorado Basin Stakeholders Moving Forward to Address Challenges Identified in the Colorado River Basin Water Supply and Demand Study: Phase 1 Report*, May 2015. http://www.usbr.gov/lc/region/programs/crbstudy/MovingForward/Phase1Report.htm; and Kaomine Vang and David Zoldoske, *Irrigation Management*, California Agricultural Water Stewardship Initiative, http://agwaterstewards.org/index.php/practices/irrigation_management.

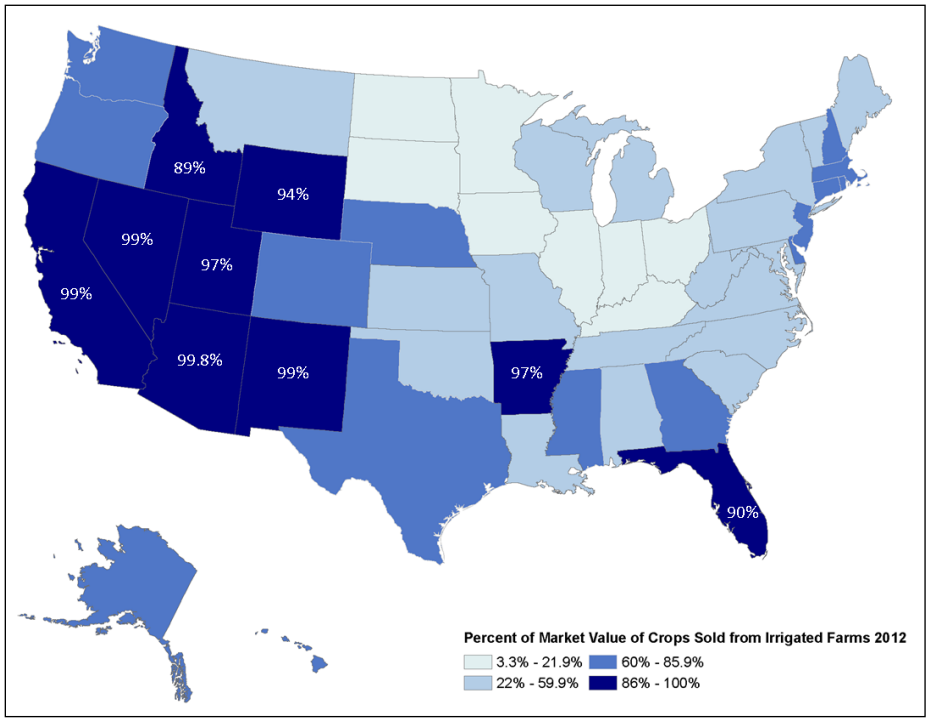
[2] U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), *2013 Farm and Ranch Irrigation Survey*, Table 27: Discontinuance of All Irrigation by Reason: 2013 and 2008, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[3] USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Table 4: Estimated Quantity of Water Applied by Source, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[4] USDA, NASS, *Irrigation: Results from the 2013 Farm and Ranch Irrigation Survey*, ACH 12-16, November 2014, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Highlights/Irrigation/Irrigation_Highlights.pdf.

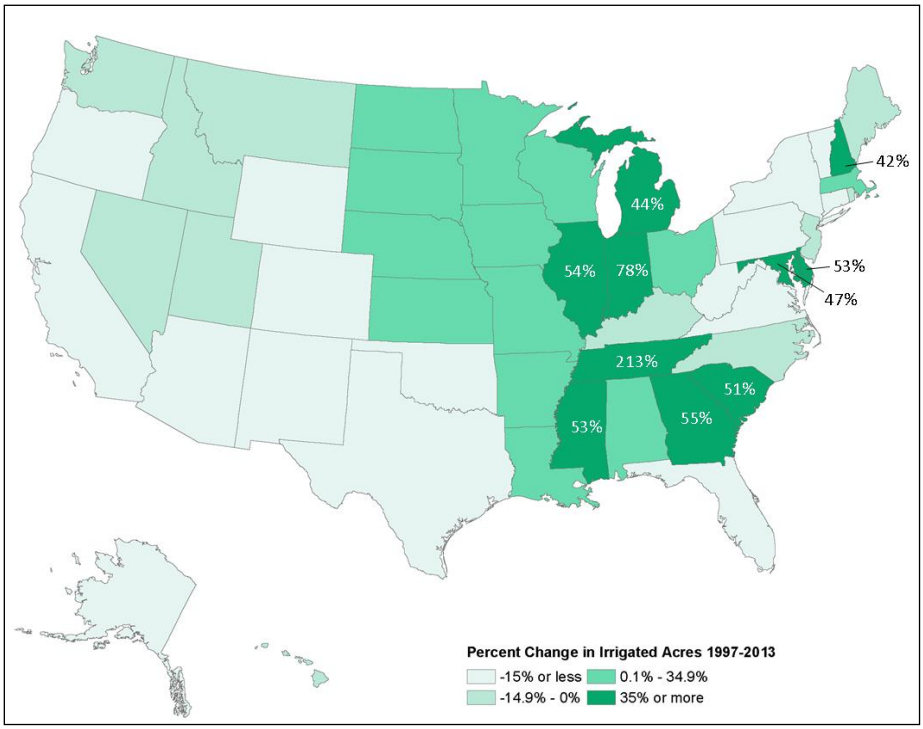
[5] USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 4 and 11, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/; USDA, NASS, *2012 United States Census of Agriculture*, AC 12-A-51, Washington, DC, May 2014, Table 11: Selected Characteristics of Irrigated and Nonirrigated Farms: 2012 and 2007, http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/st99_1_011_011.pdf. The 17 western states, also referred to in this report as the West, are defined by the Bureau of Reclamation and include Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

Figure 1. Percent of Market Value of Crops Sold from Irrigated Farms, 2012



Source: CRS from USDA, National Agricultural Statistics Service (NASS), *2012 United States Census of Agriculture*, AC 12-A-51, Washington, DC, May 2014, http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf.

Figure 2. Percent Change in Irrigated Acres in the United States, 1997-2013



Source: CRS from USDA, NASS, *Quick Stats*, http://quickstats.nass.usda.gov/.

Many stakeholders are interested in policies associated with irrigation because of its significance to U.S. agriculture and water supplies. Drought and heat events, as well as agricultural market conditions, have raised agricultural producers' interest in investing in irrigation systems and improved irrigation practices; these producers often are weighing the benefits of irrigation-related investments with their costs. Many municipal interests and customers are concerned about irrigation's role in regional water demands and how agricultural water use may affect urban water supplies. These interests would often like to see more judicious use of water in agriculture.[6] Environmental interests are concerned about irrigation's impact on water quality and water source depletion and resulting impacts on aquatic ecosystems and species. At the same time, agricultural producers are concerned about possible cuts to their right or access to water, the lack of which could alter their ability to farm or alter their current system, crop type, or yield.

A report from 1996 by the National Research Council summarized the pressures affecting the changing nature of U.S. irrigation as follows:[7]

- Water costs and demand for water are rising, which is likely to continue.
- Irrigated agriculture, as the largest and most economically marginal user of water in water-scarce areas, is vulnerable to changing water availability.
- The viability of irrigated farming may be threatened by problems, such as salinization of soils and dependence on nonrenewable water supplies.

[6] George Skelton, "Thirsty Crops Should Require State Regulation," *Los Angeles Times*, March 22, 2015, http://www.latimes.com/local/politics/la-me-cap-drought-20150323-column.html; Mark Bittman, "Making Sense of Water," *New York Times*, April 14, 2015, http://www.nytimes.com/2015/04/14/opinion/making-sense-of-water.html.

[7] National Research Council, *A New Era for Irrigation*, 1st ed. (Washington, DC: National Academies Press, 1996).

- The quality of irrigation drainage or return flows is sometimes sufficiently impaired as to limit the future reuse of that water for other purposes, including environmental uses.
- Irrigation systems and management will likely continue to evolve, moving toward advanced technologies that provide better water control.
- The ability of states, Indian tribes, and individual water users to market water could be central to increasing the flexibility of water allocation, whether for irrigation or nonirrigation uses.

Agricultural water use and irrigation practices raise a number of policy questions. For example:

- Are on-farm irrigation best management practices (BMPs), and the programs that support them, the most cost-effective use of federal funding? Are there other areas of the water supply chain or involving water users (e.g., irrigation districts, municipal, manufacturing, thermoelectric power, etc.) that could provide greater water conservation more economically and/or in greater quantities?
- How is the efficiency of irrigation BMPs at conserving water measured? Could these efficiencies be incorporated into federal conservation program implementation and funding allocations?
- Should new and emerging precision technologies, such as data analytics and drones, receive federal assistance similar to the more traditional irrigation BMPs? What level of priority should these technologies receive, and what level of water conservation do they provide?
- Should conditions be attached to federal funding for irrigation BMPs to limit agricultural consumption of conserved water (e.g., limiting new irrigated land from coming into production when federal funds are used to convert to efficient irrigation systems)? If consumption restrictions were required, what impact would this have on irrigation BMP adoption? What impact would this have on voluntary federal conservation program participation? What would the conserved water be used for, and who controls it? If the conserved water is diverted to another consumptive purpose (e.g., urban use), is it truly "conserved?"

This report primarily addresses two U.S. on-farm irrigation topics: (1) the adoption of irrigation technologies and best management practices and (2) water use associated with irrigation. The report is intended to provide an overview of on-farm irrigation and does not cover storage and conveyance prior to the farm or how irrigation adoption may alter other farm practices, such as the use of fertilizers and pesticides or impacts off-farm (e.g., groundwater and surface water quality concerns).[8] While these issues are significant to understanding the full system that supports irrigated agriculture and the potential environmental impacts of irrigation, they are beyond the purpose and scope of this report.

[8] Irrigation comes with a suite of environmental management challenges and options. A 1982 incident of waterfowl and shorebird reproductive failures, deformities, and mortalities at the Kesterson National Wildlife Refuge in the San Joaquin Valley of California is one example that raised attention to the issue of farm irrigation drainwater quality. Some of the location-specific irrigation drainwater constituents that have been identified as concerns include arsenic, boron, copper, DDT, mercury, molybdenum, salinity selenium, and zinc (U.S. Department of the Interior, *National Irrigation Water Quality Program*, August 2001, http://www.usbr.gov/niwqp/pdf/niwqpbrochure.pdf). The USDA has identified improvements in irrigation water management as essential to meeting national priorities for reducing agriculturally induced pollution, such as surface water and groundwater contamination and soil erosion and sedimentation.

Irrigation Trends in the United States

Irrigation has played a significant role in the development and economy of the United States. It was critical in the settlement of the West and agricultural reinvention after the Dust Bowl. While irrigation has ancient roots, technological developments (e.g., pumps, plastics, computers, and sensors) have transformed modern irrigated agriculture.[9] The benefits of irrigation for the nation's agricultural industry have been expansive; however, the application of irrigation technologies and the concomitant changes in the industry have not been without their costs. These costs include but are not limited to associated infrastructure (e.g., dams and conveyance facilities), programs supporting use (e.g., federal assistance for irrigation investments and efficiency improvements), and potential effects on other current and future water users and the environment.

National Trends

The two primary measurements of irrigation water use are water withdrawals and water consumption. While irrigation water withdrawals measure the amount of water applied to lands to assist in crop and pasture growth, water consumption from irrigation refers to the water that is taken in by a plant or evaporated without returning to water sources through runoff or percolation. Although irrigation is the second-largest source of water withdrawals in the United States behind thermoelectric power, irrigation withdrawals have decreased by 23% since their peak in 1980.[10] From 2005 to 2010, irrigation withdrawals dropped 9% nationally.[11] It is unclear, however, whether this decline in withdrawals has led to a decline in water consumption.[12] This is because as irrigation efficiency improves, often less water returns to surface or groundwater supplies through runoff or percolation.

Brief Glossary of Terms

17 Western States (The West)—Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

Eastern States (The East)—All contiguous states not included in the 17 western states.

Gravity Irrigation—Irrigation systems that divert water from a source to flood over a crop area via land-forming measures, including canals, ditches, basins, and furrows.

Microirrigation—Irrigation systems that consist of several types of low-pressure, highly efficient irrigation systems that apply water directly to the root zone of crops.

Sprinkler Irrigation—Irrigation systems that spray water into the air through a sprinkler or nozzle over a crop area to provide adequate soil moisture for crops.

[9] Modern irrigation methods arose in the United States in the mid-19th century with the settlement of the Utah Great Salt Lake Basin. In 1902, Congress responded to growing support for federal irrigation assistance in the west by passing the Reclamation Act, which ultimately led to the construction of over 100 water projects in 17 western states, making extensive settlement and large-scale irrigation projects on western lands possible.

[10] Molly A. Maupin, Joan F. Kenny, and Susan S. Hutson, et al., *Estimated Use of Water in the United States in 2010*, U.S. Geological Survey, Circular 1405, November 5, 2014, http://pubs.usgs.gov/circ/1405/.

[11] Ibid.

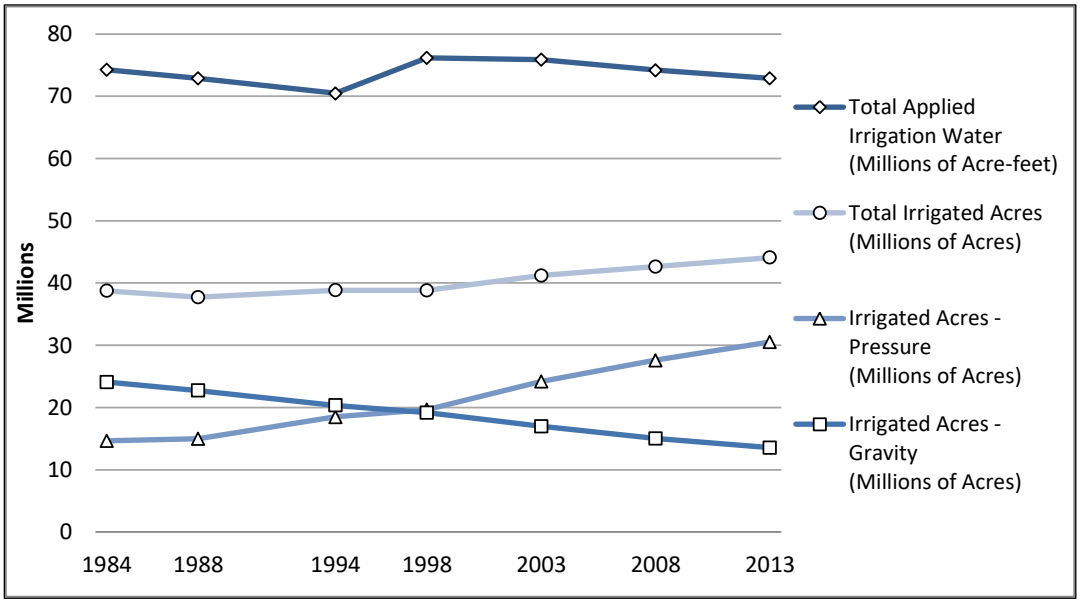
[12] There are no recent authoritative national estimates on water consumption. Previously water consumption was estimated by the U.S. Geological Survey; however, it has not produced consumption estimates since 1985.

On-Farm Trends

As **Figure 2** illustrates, changes in the amount of land irrigated across the United States over time vary by region. Since 2003, only four western states have seen an increase in irrigated acres, while the rest have seen a reduction. Several eastern states, on the other hand, have seen a significant increase in irrigated acres over this same time period; seven states increased irrigation by 50% (Delaware, Georgia, Illinois, Indiana, Mississippi, South Carolina, and Tennessee).

Since the 1980s, farmers shifted from gravity irrigation to pressurized sprinklers and microirrigation.[13] This shift has been especially pronounced in 17 western states, with gravity irrigation declining from almost 62% of irrigated acres in 1984 to 30% by 2013.[14] As shown in **Figure 3**, irrigated land in the West increased by 1.7 million acres during this same time period, while applied irrigation water declined by over 1.37 million acre-feet (AF).[15] There have been

Figure 3. Irrigated Acres and Applied Irrigation Water, Western States 1984-2013



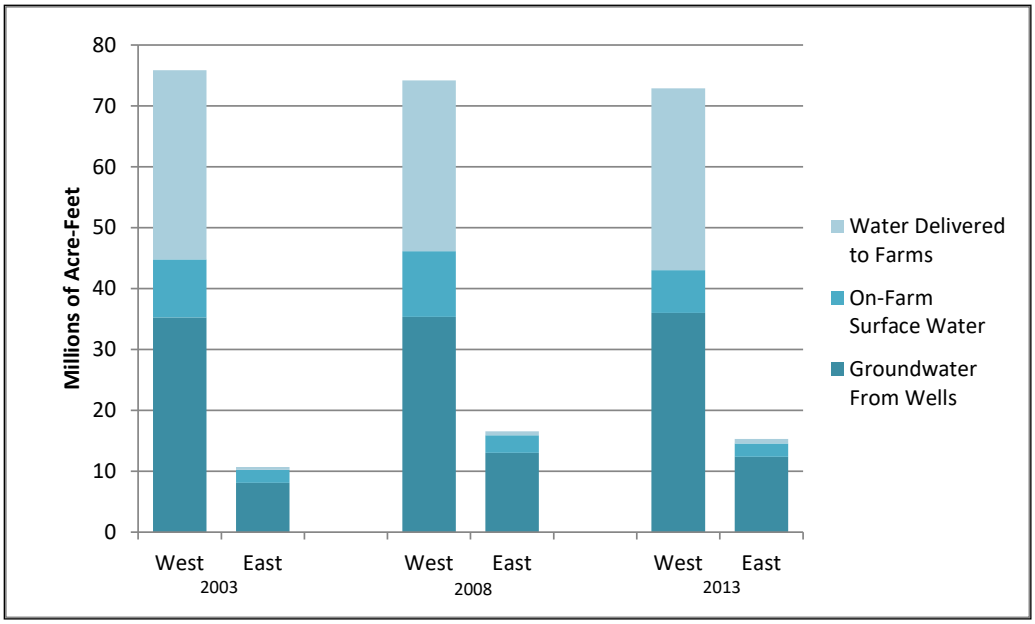
Source: CRS from Glenn Schaible and Marcel Aillery, *Irrigation and Water Use: Background*, USDA, Economic Research Service (ERS), June 7, 2013, http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/background.aspx; and USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 4, 29, 30, and 31, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[13] For a brief description of common irrigation technologies, see **Figure 10**.

[14] USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Table 28: Land Irrigated in the Open by Method of Water Distribution: 2013 and 2008, https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/; U.S. Department of Commerce, Bureau of the Census, *1984 Farm and Ranch Irrigation Survey*, AG84_SR-1, Table 4: Land Irrigated by Method of Water Distribution 1984, June 1986, http://catalog.hathitrust.org/Record/009152634.

[15] An acre-foot (AF) of water is the volume of water it takes to cover one acre of land with a one foot of water. Sources: USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 4 and 11; and U.S. Department of Commerce, Bureau of the Census, *1984 Farm and Ranch Irrigation Survey*, AG84_SR-1, Table 6: Estimated Quantity of Water Applied by Source 1984, June 1986, http://catalog.hathitrust.org/Record/009152634.

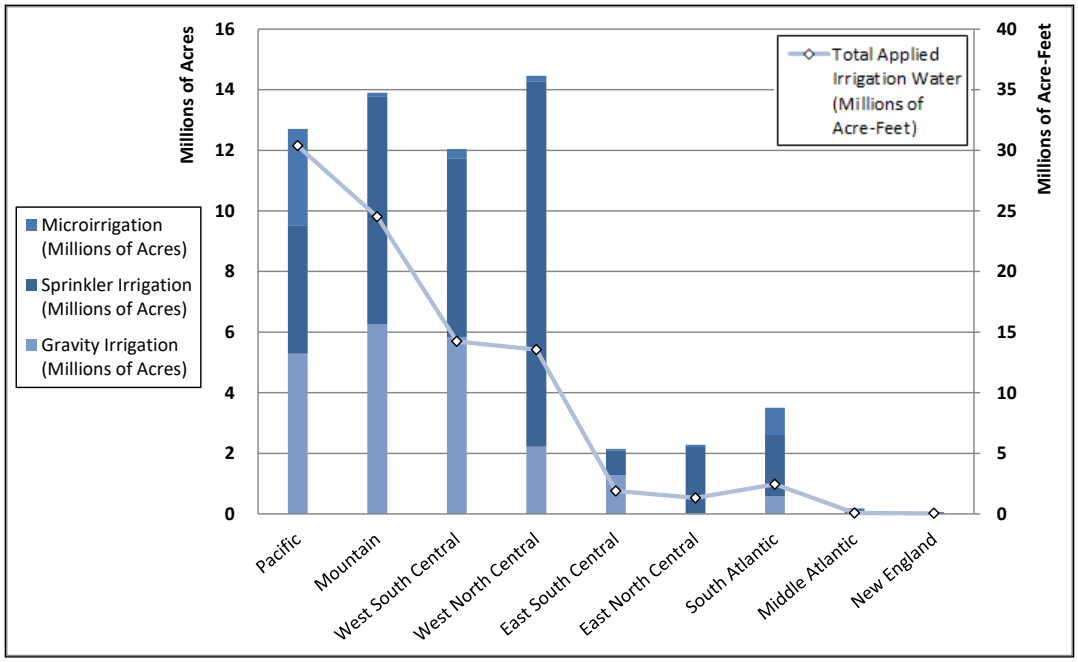
Figure 4. Sources of Applied Irrigation Water in the West and East, 2003-2013



Source: CRS from USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/; and USDA, NASS, *2008 Farm and Ranch Irrigation Survey*, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/.

Notes: The West refers to the 17 western states previously identified, and the East refers to all contiguous states not included in the 17 western states. Data does not include water withdrawals from institutional, research, and experimental operations or horticultural crops grown under protection in greenhouses and other protective structures that regulate light, shade, and temperature.

Figure 5. Irrigation Technologies by Acres and Applied Water by Acre-Feet by Census Division, 2013



Source: CRS from USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 6 and 28, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

Notes: Divisions are based on the nine U.S. Census Bureau Divisions. For a state-by-state breakdown, see **Appendix A.** Data do not include water withdrawals or irrigation methods from institutional, research, and experimental operations or horticultural crops grown under protection.

fluctuations in the amount of irrigation water applied over time with the current trend of decline in water application beginning in 1998. **Figure 4** shows that although irrigation withdrawals from on-farm surface water and water delivered to farms in the West has decreased by about 2.5 million and 1.2 million AF, respectively, since 2003, groundwater withdrawals have increased by over 740,000 AF. Even with this overall decline in irrigation withdrawals, irrigation withdrawals remain highest in the western-most portions of the United States (**Figure 5**).[16]

Growth in irrigated acres in the West is small when compared to increases in the East. Since 1984, irrigated land in eastern states has grown by over 8.7 million acres.[17] **Figure 4** shows that groundwater withdrawals have been the primary withdrawal source for irrigation in eastern states. Withdrawals peaked in 2008, with an overall increase of 4.3 million AF since 2003. This trend in increased irrigated acres in the East has been attributed to increased commodity prices and yield, drought episodes, and low-cost access to groundwater.[18] In many cases, this expanded use of

[16] Although the West North Central division (**Figure 5**) had the highest number of irrigated acres in 2013, total acre-feet applied was half of water use in the Pacific division. This may be influenced by, but not limited to, climate conditions, soil infiltration rates, and the irrigation efficiency of sprinkler systems, which make up the majority of systems used in the West North Central division.

[17] U.S. Department of Commerce, Bureau of the Census, *1984 Farm and Ranch Irrigation Survey*, Table 2, http://catalog.hathitrust.org/Record/009152634; and USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Table 2, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[18] Glenn Schaible and Marcel Aillery, *Irrigation and Water Use: Background*, USDA, Economic Research Service (ERS), June 7, 2013, http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/background.aspx.

groundwater for irrigation has contributed to a decline in aquifer levels and raised environmental concerns.[19]

Irrigation Efficiency

While there are many definitions that can be used for this term, irrigation efficiency in this report refers to the percentage of applied irrigation water that is beneficially used and not lost to evaporation or seepage during on-farm conveyance, percolation, or runoff.[20] This is determined by several factors, including irrigation system performance, uniformity of water application, and crop response to irrigation.[21] One factor to consider in determining irrigation efficiency is the rate of evapotranspiration.[22] Climate conditions, like length of sunlight hours, intensity of sunlight, temperature, humidity, wind speed, and canopy development, influence evapotranspiration rates, which determine the crop water requirement.[23] Another determinant of irrigation efficiency is the water conveyance system. Irrigation canals that are not well constructed or maintained can lead to conveyance losses of up to 50%.[24]

Irrigation Technologies from State to State

The types of irrigation systems most commonly used and the amount of land irrigated can vary widely from state to state. **Figure 6** highlights this difference in select states across the country. Arkansas irrigates more acres than all but two states (i.e., Nebraska and California) and uses gravity irrigation for over 77% of irrigated acres, while using microirrigation on just 0.5% of irrigated land. New Hampshire, on the other hand, uses microirrigation (51%) and sprinkler irrigation (46%) on the majority of irrigated land in the state while using gravity irrigation on only 3% of irrigated acres. Although the state only irrigated 4,500 acres in 2013, which is a very small percentage of overall irrigated acres in the United States, New Hampshire is the only New England state to see irrigation grow by more than 35% since 1997 and have irrigated farms produce over 60% of the market value of crops sold in the state in 2012. California, Nebraska, Georgia, and Michigan are highlighted because they are major irrigation-using states within their respective regions.

Efficient irrigation systems are often thought of as allowing the same level of crop production as less efficient systems while leaving additional water in the hydrological system for further use downstream. Studies have shown, however, that in some cases efficient irrigation systems may lead to greater water consumption.[25] In a study of irrigation subsidies, researchers found that

[19] Ibid.

[20] This report does not cover the efficiency of off-farm conveyance systems related to irrigation.

[21] B.A. Stewart and Terry A. Howell, "Irrigation Efficiency," in *Encyclopedia of Water Science* (New York: Marcel Dekker, 2003), pp. 467-472.

[22] Evapotranspiration refers to evaporation for the soil surface and transpiration from plants.

[23] Martin Burton, *Irrigation Management: Principles and Practices* (Oxfordshire: The Centre for Biosciences and Agriculture International, 2010), http://www.lrc.tnu.edu.vn/upload/collection/brief/7698_9781845935160.pdf.

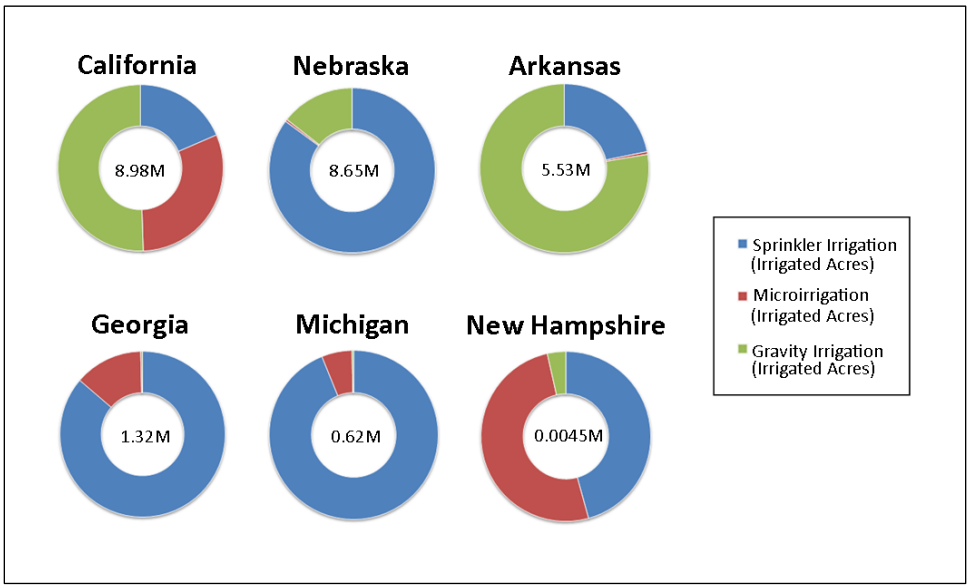
[24] Karina Schoengold and David Zilberman, "Chapter 58: The Economics of Water, Irrigation, and Development," in *Handbook of Agricultural Economics*, ed. Robert Evenson & Prabhu Pingali, vol. 3 (Elsevier B.V., 2007), pp. 2933-2977.

[25] Frank A. Ward and Manuel Pulido-Velazquez, "Water Conservation in Irrigation Can Increase Water Use," *Proceedings of the National Academies of Sciences*, vol. 105, no. 47 (2008), pp. 18215-18220, http://www.pnas.org/content/105/47/18215.full; Reagan M. Waskom, "Water Sustainability in Agriculture: Optimizing Agricultural Water for Food, the Environment and Urban Use," Plenary Session at the National Agricultural Biotechnology Council (NABC Report 24), Ithaca, NY, 2012, pp. 185-194, http://nabc.cals.cornell.edu/Publications/Reports/nabc_24/24_4_2_Waskom.pdf; Robert G. Evans and E. John Sadler, "Methods and Technologies to Improve Efficiency of Water Use," *Water Resources Research*, vol. 44 (July 29, 2008), http://onlinelibrary.wiley.com/doi/10.1029/2007WR006200/epdf; Schoengold and Zilberman, 2007; and Schaible and Aillery, 2013.

increasing water conservation subsidies for drip irrigation in the Upper Rio Grande Basin would increase water consumption and crop yield while also increasing acreage irrigated.[26] While some case studies support this, it remains unclear if expanded irrigation resulting from water conservation occurs nationwide and to what extent.

Figure 6. Irrigation Technologies in Select States, 2013

Distribution of technologies as a proportion of total irrigated acres per state, in millions of acres



Source: CRS from USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 29, 30, and 31, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

Notes: For related statistics on all states, see **Appendix A**.

Microirrigation may be more efficient than gravity irrigation, but gravity irrigation typically consumes less water than microirrigation. This is because the majority of water that is not lost to evapotranspiration through gravity irrigation is returned to surface or groundwater sources through runoff and deep percolation.[27] This means that water that is not taken in by plants through evapotranspiration could potentially be put to subsequent beneficial use.[28] Additionally, even if measures are taken to limit increased water consumption (e.g., limiting additional irrigated crop acreage after conversion to efficient irrigation systems), efficient irrigation technologies may

[26] Ward and Pulido-Velazquez, 2008.

[27] Ibid.

[28] A net increase in recharge from surface irrigation only occurs if irrigation withdrawals come from surface water sources. Another consideration of groundwater depletion is soil type. For example, fine-grained soils, commonly found in the Central High Plains, limit groundwater recharge from irrigation water. Further, local irrigation efficiency estimates do not necessarily reflect efficiency levels at a basin scale so wide-scale averages should be taken with the knowledge that efficiency levels may vary from location to location. For more information, see Bridget R. Scanlon, Claudia C. Faunt, Laurent Longuevergne, et al., "Groundwater Depletion and Sustainability of Irrigation in the US High Plains and Central Valley," *Proceedings of the National Academies of Science*, vol. 109 no. 24 (2012), pp. 9320-9325, http://www.pnas.org/content/109/24/9320.full; and Chris Perry, Pasquale Steduto, and Richard G. Allen, et al., "Increasing Productivity in Irrigated Agriculture; Agronomic Constraints and Hydrological Realities," *Agricultural Water Management*, vol. 96, no. 11 (November 2009), pp. 1517-1524.

encourage farmers to grow more profitable, water-intensive crops.[29] This means that adopting more-efficient irrigation technologies may not necessarily result in less water consumed overall.

Irrigation Technologies and Best Management Practices (BMPs)

A common classification for irrigation systems based on energy and pressure requirements divides irrigation methods into two categories: pressure systems and gravity systems.[30] These systems are differentiated from each other by the method used to deliver water to crops and cover most types of irrigation systems in the United States. While these two categories cover basic irrigation, precision technologies to increase irrigation efficiency and reduce costs complement these systems and are increasingly becoming a common part of modern irrigation systems.

Best management practices (BMPs) for irrigation center around how water is managed on a farm, including improved conveyance, irrigation scheduling, and application methods. The BMPs discussed below are based on select practices identified by USDA's Natural Resources Conservation Service (NRCS). Not all irrigation technologies are considered BMPs, and those listed do not constitute a recommendation or endorsement. Additionally, some BMPs listed could apply to both pressure and gravity irrigation systems, while others are limited to one type of system.[31] The success or failure of a BMP depends on a number of factors and in some cases requires the application of more than one practice. For a more extensive list of BMPs, see **Appendix B**.

Pressure Systems

Pressure systems pump water through tubing or pipes where water is applied to crops through an applicator like a sprinkler or perforated pipe. Pressure systems are commonly separated into two sub-categories: sprinkler and microirrigation systems. Sprinkler irrigation (**Figure 7**) uses high- to medium-pressure systems to spray water through applicators, creating artificial precipitation, while microirrigation (**Figure 8**) uses low-pressure systems to apply water directly to the root zone of crops. As shown in **Table 1**, pressure irrigation systems make up roughly 58-65% of irrigation systems used in the United States. Major pressure systems include center pivot, linear move tower, solid set or permanent, slide roll or wheel move, big gun or traveler, hand move, and drip, trickle, or low-flow micro sprinklers (**Figure 10**). These systems are generally more efficient than gravity systems and can be used to grow most crops.[32] Although the operational labor requirement for these systems can be low, the initial investment costs can be high.[33]

[29] Evans and Sadler, 2008.

[30] M. H. Ali, *Practices of Irrigation and On-Farm Water Management: Volume 2* (New York: Springer, 2011).

[31] For example, irrigation water management plans may be developed on both pressure and gravity irrigation systems. Sprinkler irrigation, however, is generally limited to pressure systems.

[32] Ali, 2011.

[33] Ibid; Kenneth H. Solomon, *Irrigation Notes: Irrigation System Selection*, Center for Irrigation Technology, CATI Publication No. 880105, Fresno, CA, January 1988, http://cwi.csufresno.edu/wateright/880104.asp.; Burton, 2010.

Irrigation Water Management Plan

An irrigation water management plan requires intentional preparation to manage the timing and application of water through irrigation systems in order to maintain appropriate soil moisture levels, reduce soil erosion, maximize plant growth, lower energy consumption, and increase water efficiency. This plan may include several irrigation BMPs: microirrigation, sprinkler irrigation, ditch lining, land leveling, tailwater recovery, etc.

Figure 7. Sprinkler Irrigation

Source: USDA NRCS, "Sprinkler System: Practice Introduction."

Notes: A center pivot irrigation system.

Sprinkler Irrigation

A sprinkler system is a general term to describe the most common types of pressure irrigation systems like center pivot, side roll, and linear move tower irrigation (**Figure 10**). These systems spray water into the air through a sprinkler or nozzle over a crop area to provide adequate soil moisture for crops. Sprinkler systems are also used for crop cooling, frost protection, and dust control.

Figure 8. Microirrigation

Source: USDA NRCS, "Conservation Practice Standard Overview: Irrigation System, Microirrigation (441)."

Notes: Surface drip irrigation system.

Microirrigation

Microirrigation consists of several types of low-pressure, highly efficient irrigation systems including surface drip, micro sprinkler, and sub-surface drip irrigation (**Figure 10**). It is typically a more efficient irrigation method compared to sprinkler and gravity irrigation because it applies water directly to the root zone of crops.

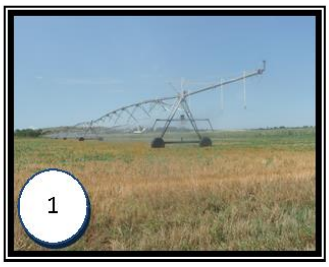
Low-Energy Precision Application Irrigation

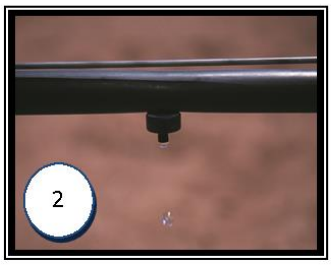
This enhancement converts standard center pivot irrigation systems to low-energy precision application (LEPA) irrigation systems. LEPA systems apply water directly into circular furrows through nozzles placed close to the soil surface to reduce evaporation losses and energy consumption.

Figure 9. Low-Energy Precision Application Irrigation

Source: USDA NRCS.

Figure 10. Common Irrigation Technologies in the United States





1.	Center Pivot	Sprinklers are attached to a wheel-driven frame that rotates around a central point to irrigate a large circular area.
2.	Surface Drip	Surface drip irrigation uses small diameter tubing and to drip water directly to the root zone of plants through emitters.
3.	Side Roll or Wheel Move	Sprinklers are attached to a wheel-mounted lateral pipe. Self-aligning sprinkler heads are used so that the sprinklers are always upright.
4.	Low-Flow Micro Sprinklers	Micro sprinklers are similar to surface drip systems, except they spray water at low pressures over a wider area instead of dripping the water directly onto the root zone of a plant.
5.	Big Gun or Traveler	A large, gun type sprinkler that is periodically moved by tractor.
6.	Solid Set and Permanent	Sprinklers are attached to either to an above ground portable pipe system or a permanent buried system. Sprinklers are typically arranged in a diamond or triangular pattern.
7.	Hand Move	Sprinklers are attached to an above ground portable lateral pipe system that can be moved by hand.
8.	Furrow	Water is applied to the end of small parallel channels. The water then flows down the slope of a field and seeps into the soil.
9.	Sub-Surface Irrigation	Subsurface irrigation is a microirrigation system that is buried in the ground, which allows the application of water directly to the root zone of a plant with very little evaporation loss.
10.	Linear Move Tower	Sprinklers are attached to a continuous, self-moving system that irrigates a rectangular area.

Source: CRS and USDA NRCS.

Table 1. Major Irrigation Technologies: Use in the United States, 2013

	Farms	Irrigated Acres (In Thousands)
Pressure Systems	122,000	36,200-39,800 (58%-65%)
Center Pivot	57,000	27,900
Surface Drip	41,000	2,600
Side Roll or Wheel Move	17,000	1,900
Solid Set and Permanent	21,000	1,500
Low-Flow Micro Sprinklers	15,000	1,300
Hand Move	30,000	800
Sub-Surface Drip	6,000	800
Linear Move Tower	5,000	600
Big Gun or Traveler	8,000	600
Other Sprinkler System	12,000	1,700
Other Drip, Trickle, or Low-Flow Micro Systems	4,000	300
Gravity Systems	85,000	21,500-26,200 (35%-42%)
Furrow	43,000	10,500
Controlled Flooding	37,000	8,500
Uncontrolled Flooding	12,000	1,800
Other Gravity Systems	6,000	800
Total	207,000	57,700-66,000

Source: CRS from USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 29, 30, and 31, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/; Molly A. Maupin, Joan F. Kenny, and Susan S. Hutson, et al., *Estimated use of water in the United States in 2010*, U.S. Geological Survey, Circular 1405, November 5, 2014, http://pubs.usgs.gov/circ/1405/.

Notes: All numbers are rounded estimates derived from USDA or USGS data. This is not a comprehensive list of all irrigation technologies used in the United States. These are major irrigation systems used in the United States as designated by the 2013 Farm and Ranch Irrigation Survey. For definitions of each irrigation method, see **Figure 10**. USGS data is used for the estimated range of irrigated acres using pressure or gravity systems, and does not include statistics on specific irrigation system subcategories.

Gravity Systems

Gravity systems, which make up 35 to 42% of irrigation systems in the United States, divert water from a source to flood over a crop area via land-forming measures, including canals, ditches, basins, and furrows (**Figure 10**). While controlled flooding methods, like basin irrigation, border irrigation, and furrow irrigation, use land-forming measures to increase efficiencies,

uncontrolled flooding, which is the oldest and simplest form of irrigation, does not.[34] The irrigation efficiency of gravity systems is generally less efficient than pressure systems.[35] These systems can have a low to medium initial investment cost and a medium to high operational labor requirement. Most gravity systems are suited for close-growing crops, like rice. Furrow irrigation systems, however, may be used for row crops like potato and corn.

Irrigation Land Leveling

Irrigation land leveling (**Figure 11**) is the process of reshaping a field to make sure water is applied uniformly to a crop area without creating puddles in low sections and dry spots in high sections. Land leveling can increase gravity irrigation efficiency, reduce erosion, and prevent water logging of soil or crops.

Figure 11. Laser-Leveling Irrigation Land

Source: Tim, McCabe, USDA NRCS.

Field Ditch, Canal, or Lateral

A field ditch, canal, or lateral is a commonly used method of delivering water from a source to an irrigation system through permanent channels.

Irrigation Ditch Lining

Irrigation ditch lining is a lining installed in a canal, lateral, or ditch to limit water loss due to seepage while in transit to a crop area for application. Canal linings can increase conveyance efficiency by an amount that can vary based on soil type and length of the canal.[36] Ditch lining may be constructed from numerous materials, including concrete, PVC, and polypropylene.[37]

[34] Burton, 2010.
[35] Ali, 2011.
[36] Food and Agriculture Organization (FAO), *Irrigation Water Management: Irrigation Scheduling*, Training Manual no. 4, Rome, 1989, "Annex I: Irrigation Efficiencies," http://www.fao.org/docrep/t7202e/t7202e08.htm#annex%20i:%20irrigation%20efficiencies.
[37] Robert Burns, *What's the Best Irrigation Canal Liner?* Texas A&M University Department of Biological and Agricultural Engineering, May 24, 2012, http://baen.tamu.edu/2012/05/whats-the-best-irrigation-canal-liner/.

Figure 12. Tailwater Recovery and Pump

Source: USDA NRCS.

Tailwater Recovery

Tailwater recovery refers to reusing excess water from gravity irrigation that is not initially infiltrated into the soil. To avoid potential water contamination through runoff or waterlogging of crops at the end of a slope, a tailwater recovery system may be built to convey water back to the irrigation system for reuse through a pump and pipeline or ditch system (**Figure 12**).

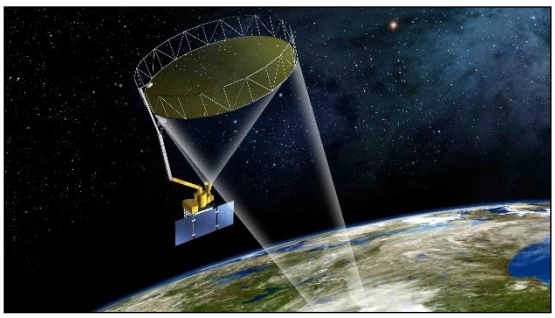
Irrigation Reservoir

An irrigation reservoir provides a storage place for water to use for irrigation. The size of the reservoir depends on how much water is available and needed for irrigated crops, and the reservoir water level may be maintained by surface or groundwater. Irrigation reservoirs may be built by constructing a dam, embankment, pit, or tank.

Precision Technologies

The incorporation of precision technologies into the agricultural industry has grown rapidly in recent years, especially in irrigation. Precision technologies, such as satellite data, sensor networks, data analytics, and drones, increase irrigation efficiency and have been reported to reduce input costs and increase crop yield. Over the last several years, technology companies have become increasingly involved in the agricultural sector, offering technology and data services to help farmers maximize profits.[38]

Figure 13. Soil Moisture Active Passive (SMAP)



Source: NASA, 2014.

Notes: Artist's rendering of NASA's Soil Moisture Active Passive (SMAP).

Satellite Data

A collaborative project between the NASA Jet Propulsion Laboratory and USDA ARS Hydrology and Remote Sensing Laboratory launched a satellite under the mission title SMAP (Soil Moisture Active Passive) (**Figure 13**).[39] The satellite gathers soil moisture data from around the world without the use of terrestrial sensors or other field measurements. While SMAP's radar stopped transmitting in July 2015, supplemental data and its functioning radiometer has allowed the project to continue.[40] Governments and agricultural producers could be able to use this data to

[38] For additional information, see CRS Report R44331, *Big Data in U.S. Agriculture*.

[39] For more information, visit the official SMAP website at http://smap.jpl.nasa.gov/.

[40] NASA, Jet Propulsion Laboratory, "NASA Soil Moisture Radar Ends Operations, Mission Science Continues," press release, September 2, 2015, http://smap.jpl.nasa.gov/news/1247/nasa-soil-moisture-radar-ends-operations-mission-science-continues/.

better inform decisions on when, where, and how much applied irrigation water may be beneficial.[41]

Drones[42]

Unmanned aerial vehicles (i.e., drones) can be used for aerial imagery and data collection; the information can then be combined with software to help identify trends to show how irrigation can be adjusted.

Figure 14. Remote Soil Monitoring

Source: Jeff Vanuga, USDA, NRCS.

Sensor Networks and Data Analytics

Sensor networks can be used to monitor plant water status, plant evapotranspiration, or volumetric water content of the soil. Data analytics refers to the use of real-time data on energy consumption, environmental conditions, and information gathered from these sensor networks to improve decisions. This information can then be used for irrigation system automation, which adjusts the amount and frequency of water applied based on the data gathered (**Figure 14**).

Regional Weather Networks

Information from regional weather networks can be used to track crop evapotranspiration. By combining this information with precipitation and soil moisture data, an accurate irrigation schedule can be established.

Remote Monitoring Notification of Irrigation Pumping Plants

A remote monitoring notification system wirelessly transfers real-time information to alter irrigation operations (e.g., altering pumping). Remotely collected information can help reduce and prioritize field visits and reduce overall water applied to fields.

[41] Personal communication with personnel at the USDA ARS Hydrology and Remote Sensing Laboratory on June 24, 2015.

[42] On August 29, 2016, new Federal Aviation Administration rules governing small unmanned aircraft systems went into effect. The new rules set guidelines that allow the commercial operation of drones (under 55 pounds) to be flown under 400 feet and within the pilot's visual line of sight. Operators must also register the drone and pass an aeronautics knowledge test. For additional information, see http://www.faa.gov/news/updates/?newsId=86305.

Computerized Hole Selection for Poly-Pipe

Poly-pipe is used in furrow irrigation and is a flexible plastic pipe made from polyethylene resins that expand when full of water. Computer software is used to optimize hole sizes for poly-pipe, which can decrease applied water and irrigation runoff (**Figure 15**).

Figure 15. Poly-Pipe Irrigation

Source: USDA, NRCS, *Water Quantity Enhancement Activity*, WQT12, October 2, 2014.

Benefits of BMP Implementation

The implementation of irrigation BMPs can further increase irrigation efficiency by creating greater precision for water application. This can reduce the cost of production and ensure that all areas of a field are more evenly watered. On average, irrigated yields are roughly double that of non-irrigated crops.[43] As a result, irrigation can also allow producers to grow higher value crops and extend growing seasons. In some cases, irrigation BMPs enhance production of higher-value specialty crops, including fruits, vegetables, and nuts, by allowing water to flow to crops only when needed. This not only reduces the cost of applying water but may prevent problems from overwatering, such as increased disease and pest activity, root damage, and reduced yields.

The controlled environment of an irrigation system can also be simultaneously used for the application of other production-related inputs, such as nutrients and pesticides. Depending on the system, some irrigation BMPs allow synthetic nutrients and pesticides to be mixed with irrigation water and distributed concurrently. This can also reduce costs and provide more precise application.

Barriers to BMP Implementation

Irrigation technologies vary across the United States, where implementation choices are sometimes limited by cost, crop type, climate, soil, labor and technology requirements, and water quality and quantity available.

Cost and Financial Considerations

Capital and operational costs of irrigation systems can influence the adoption of efficient irrigation technologies by agricultural producers. For this reason, some have suggested that adopting efficient irrigation systems is typically not motivated by water conservation, but rather through potential economic gains of increased crop yield.[44] Because of the generally higher costs of efficient irrigation systems, growers of high-value crops were among the first to adopt drip irrigation systems, while growers of low-value crops are less likely to invest in costly, albeit more

[43] Jorge A. Delgado, Peter M. Groffman, and Mark A. Nearing, et al., "Conservation Practices to Mitigate and Adapt to Climate Change," *Journal of Soil and Water Conservation*, vol. 66, no. 4 (July/August 2015), pp. 118A-129A, http://www.jswconline.org/content/66/4/118A.full.pdf+html.

[44] Frank A Ward, "Economic Impacts on Irrigated Agriculture of Water Conservation Programs in Drought," *Journal of Hydrology*, October 2013.

efficient, irrigation systems.[45] According to USDA's 2013 Farm and Ranch Irrigation Survey (FRIS), 32% of respondents reported that they could not finance irrigation system improvements, while 25% reported that improvements would not cover installation costs.[46] **Table 2** shows that high-efficiency systems, like micro sprinklers and sub-surface drip, can be far more costly than gravity systems like furrow irrigation.

Another cost consideration for agricultural producers when selecting an irrigation system is the cost of developing a water supply. These costs can include drilling a well and operating pumps or building an on-farm storage facility. The costs of developing a water supply may impact a producer's decision to adopt efficient pressure systems. For example, the cost of establishing a water supply from groundwater, which varies based on pumping depth and energy costs, is generally more expensive than surface water.[47] As a result, high-efficiency pressure systems are commonly found in areas where there is a heavy reliance on groundwater.[48] Alternatively, areas with adequate surface water supplies are less likely to adopt efficient irrigation systems because low water development costs make gravity irrigation economically feasible. Growers in drought-prone areas that typically rely on surface water, however, are more likely to adopt more efficient irrigation systems.[49]

Table 2. Cost Estimates for Select Irrigation Technologies

	Est. Capital Cost per Acre
Low-Flow Micro Sprinklers	$2,800
Sub-Surface Drip	$1,200 - $1,800
Surface Drip	$860
Linear Move Tower	$850
Center Pivot	$340 - $620
Side Roll or Wheel Move	$610
Big Gun or Traveler	$590
Furrow	$210

Source: CRS from T. Scherer, "Selecting a Sprinkler Irrigation System," *NDSU Extension Service* (January 2010), https://www.ag.ndsu.edu/pubs/ageng/irrigate/ae91.pdf; "441 – Irrigation System, Microirrigation," USDA – Natural Resources Conservation Service (December 2014), https://efotg.sc.egov.usda.gov/references/public/CO/RegionalScenarioDetails_FY16.pdf; S. Amosson et al., "Economics of Irrigation Systems," Texas AgriLife Extension Service (October 2011), http://amarillo.tamu.edu/files/2011/10/Irrigation-Bulletin-FINAL-B6113.pdf.

[45] Robert F. Bevacqua, "Drip Irrigation for Row Crops," *New Mexico University Cooperative Extension Service*, Circular 573, August 2001, http://aces.nmsu.edu/pubs/_circulars/CR573.pdf; and Schaible and Aillery, 2012.

[46] USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Table 25, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[47] Dennis Wichelns, "Agricultural Water Pricing: United States," *Organization for Economic Co-Operation and Development*, 2010, http://www.oecd.org/unitedstates/45016437.pdf; and USGS, "Groundwater Use in the United States," *USGS Water Science School*, 2000, http://water.usgs.gov/edu/wugw.html.

[48] Schaible and Aillery, 2012.

[49] Eric C. Schuck, W. Marshall Frasier, and Robert S. Webb, et al., "Adoption of More Technically Efficient Irrigation Systems as a Drought Response," *Water Resources Development*, vol. 21, no. 4 (December 2005), pp. 651-662, http://www.ext.colostate.edu/drought/irr_systems.pdf.

Notes: These cost estimates were taken from specific hypothetical scenarios provided by government agencies and extension services. These are approximate costs that are meant to give a general idea of the price difference between different irrigation methods, which may vary due to multiple factors, including but not limited to location. Capital cost estimates do not include well, pump, and motor costs.

Crop Type

Irrigation system adoption is also determined by the type of crop being irrigated. For example, because high-pressure sprinklers used on perennial tree crops can saturate the trees and lead to fruit decay, these crops are better suited for drip irrigation systems.[50] While close-growing crops like rice typically require gravity irrigation, it is less effective for widely spaced field crops that do not need the total field soil saturation.[51] Recent survey data shows that many farmers in the United States are not able to utilize more efficient irrigation systems because of crop type. In some cases, this was due to physical field conditions, while other cited a high risk for reduced crop yields or poorer crop quality.[52]

Climate

Local climate conditions are another limiting factor of irrigation technology adoption. For example, drip and surface irrigation are typically more effective in windy conditions than overhead sprinklers.[53] In an arid climate, sprinkler irrigation is subject to high levels of evaporation, and subsurface irrigation can cause soil salinity problems.[54] Additionally, climate conditions affect crop evapotranspiration rates, which can affect an agricultural producer's decision for the most appropriate irrigation system.

Soil

The type of soil found in a crop production area can also be a determining factor when selecting an irrigation system. For example, sandy soils typically require a sprinkler or microirrigation method because high infiltration rates lower the efficiency of gravity irrigation.[55] While loam and clay soils can accommodate sprinkler, microirrigation, and gravity irrigation, the low infiltration rates of clay soils make it ideal for gravity irrigation.[56] Irrigation water management planning utilizes soil surveys, which evaluate the characteristics of soil in an area and can be a helpful tool in designing and implementing irrigation systems.[57]

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[50] Gareth Green, David Sunding, and David Zilberman, et al., "Explaining Irrigation Technology Choices: A Microparameter Approach," *American Journal of Agricultural Economics*, vol. 78, no. 4 (November 1996), pp. 1064-1072, http://www.jstor.org/stable/1243862.

[51] Ali, 2011.

[52] In 2013, 17% of farmers reported physical field or crop conditions limited improvements, while 16% cited risk of reduced crop yield or poorer crop quality as a barrier to irrigation efficiency improvements. USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Table 25, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[53] Burton, 2010.

[54] Ibid. and Ali, 2011.

[55] Ali, 2011.

[56] Ibid.

[57] Soil Survey Division Staff, "Soil Survey Manual," *U.S Department of Agriculture Handbook 18*, 1993, http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054262. Soil type information is available nationally through the USDA Web Soil Survey, http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Labor and Technology Requirements

The labor-technology trade-off between pressure and gravity systems is another factor to consider when selecting an irrigation system. Gravity irrigation can be a labor-intensive method compared to pressure systems and can be utilized with few technological inputs.[58] Highly automated sprinkler and drip systems, on the other hand, can require a high level of technical knowledge and a fraction of the labor of many gravity systems.[59]

Water Quality and Quantity of Applied Water

Other barriers limiting irrigation choices include water quality and quantity. Water quality can dictate the type of irrigation system that can be used. Because sprinkler and drip irrigation carry a clogging risk, sediment-heavy irrigation water is best suited for gravity irrigation.[60] Other water quality concerns, such as salinity and selenium, can be more effectively managed with sprinkler or drip irrigation because they offer greater control over the depth of water applied per irrigation.[61] The principal law that deals with water quality concerns in the nation's streams, lakes, estuaries, and coastal waters is the Federal Water Pollution Control Act, commonly known as the Clean Water Act.[62] The Clean Water Act's purpose is not to directly provide cleaner water for irrigation, but agriculture is a beneficiary of these efforts.[63]

How much water is legally available to a farmer or an irrigation district is largely determined by state water rights laws. Political, legal, and societal factors associated with water rights are not discussed in detail in this report. For additional info, see CRS CRS Report R43910, *Water Resource Issues in the 114th Congress*.

Federal Assistance

The federal government provides agricultural producers with financial assistance, technical assistance, research, and monitoring and reporting. A number of USDA agencies provide support through education, outreach, and research. Also, federal funds are provided through conservation programs to producers who adopt irrigation BMPs.

Financial Assistance

Financial assistance for irrigation BMPs adoption comes from farm bill conservation programs like Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), and Agricultural Management Assistance (AMA).[64] These programs award funding or

[58] Burton, 2010; the bulk of the labor in gravity irrigation is through land-forming measures. After establishing the system, water application can be automated.

[59] Ali, 2011.

[60] Ibid.

[61] Guy Fipps, *Irrigation Water Quality Standards and Salinity Management Strategies*, Texas Cooperative Extension, B-1667, 4-03, College Station, TX, http://soiltesting.tamu.edu/publications/B-1667.pdf.

[62] 33 U.S.C. §1251 et seq. (1972).

[63] Water quality issues related to water used by agriculture for irrigation, as well as water resulting from irrigation are not discussed in this report. For a more detailed analysis, including agricultural water-related concerns, see CRS Report R43867, *Water Quality Issues in the 114th Congress: An Overview*, Water Quality Issues in the 114th Congress: An Overview.

[64] For a more complete overview of USDA conservation programs, see CRS Report R40763, *Agricultural*

technical support to qualified agricultural producers that implement conservation practices according to predefined guidelines established by the program. Of the 17 irrigation BMPs funded through farm bill programs (**Table 3**), nearly half ($564 million) of the $1.2 billion in funding awarded between 2009 and 2014 went toward implementing sprinkler and microirrigation systems. **Figure 16** shows the majority of states receiving the highest amount of funding for irrigation BMPs are in the West, with California ($187 million) and Texas ($151 million) receiving the most funding.[65] Three southeastern states are also in the top 10: Arkansas ($93 million), Mississippi ($60 million), and Louisiana ($34 million).

As previously discussed, increasing irrigation efficiency may also reduce groundwater recharge and increase potential aquifer depletion. A study on groundwater use in the United States found that the High Plains, Mississippi Embayment, and Central Valley aquifers are being depleted at unsustainable rates.[66] These aquifers account for 93% of groundwater depletion that occurred in the United States from 2000 to 2008.[67] When looking at **Figure 16**, it is unclear if irrigation BMP funding is helping to reduce groundwater depletion or exacerbating the problem.

Table 3. Farm Bill Irrigation BMP Funding by Practice, FY2009-FY2014

Cumulative funding over six-year time period in nominal dollars (in millions)

Practice Title	FY2009-FY2014 Funding	Practice Title (Cont ...)	FY2009-FY2014 Funding
1. Sprinkler Irrigation	$336.9	10. Surface and Subsurface Irrigation	$14.6
2. Microirrigation	$227.4	11. Irrigation Ditch Lining	$10.8
3. Irrigation Pipeline	$167.4	12. Tailwater Recovery	$6.1
4. Pumping Plant	$123	13. Dam, Diversion	$1.6
5. Irrigation Land Leveling	$89.7	14. Irrigation Water Management Plan (CAPS)	$1
6. Water Well	$70.7	15. Irrigation Field Ditch	$0.3
7. Structure for Water Control	$68	16. Irrigation Canal or Lateral	$0.09
8. Irrigation Reservoir	$51	17. Transition from Irrigated to Dryland Farming and Ranching	$0.002
9. Irrigation Water Management	$35		
Total			**$1,203.8**

Source: CRS from data supplied by USDA, NRCS. The table represents the most recent information available.

Notes: Table includes data from EQIP, AMA, Agricultural Water Enhancement Program (AWEP), Wildlife Habitat Incentives Program (WHIP), and Chesapeake Bay Watershed Initiative. Definitions and practice codes for each practice can be found in **Appendix B**.

Conservation: A Guide to Programs, Agricultural Conservation: A Guide to Programs.

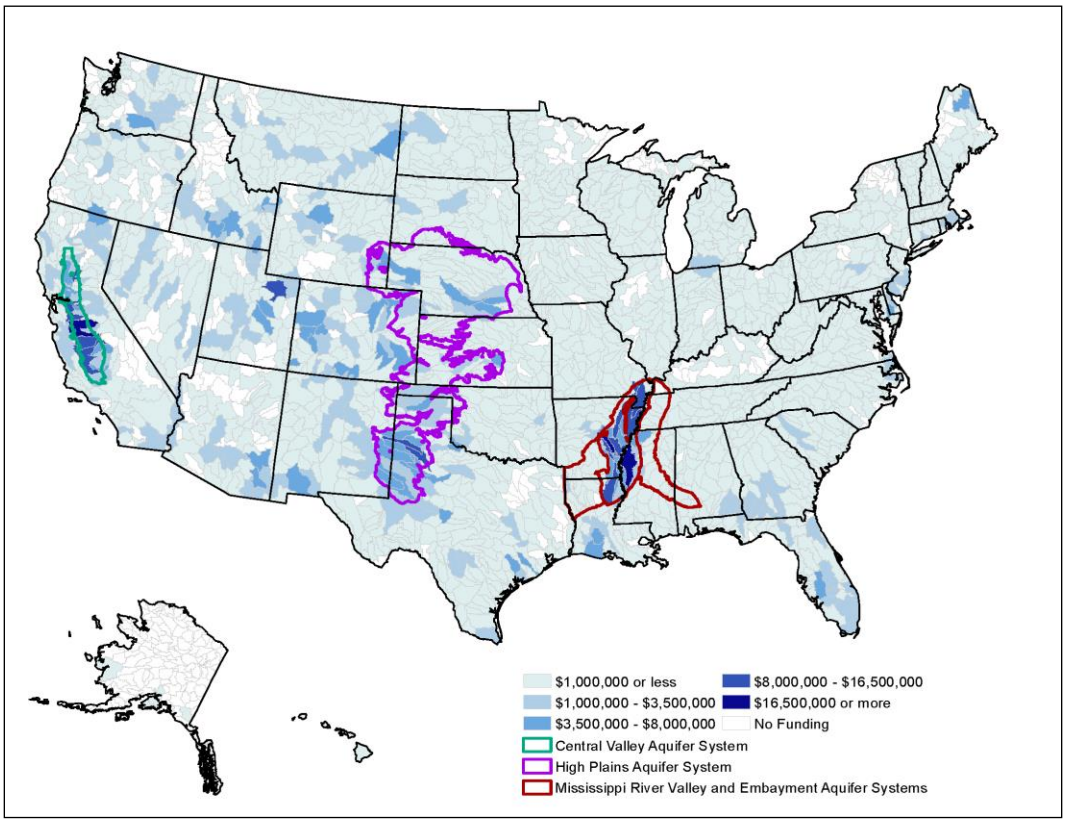
[65] For a state-by-state breakdown of EQIP irrigation BMPs funding, see **Appendix C**.

[66] Landon Marston, Megan Konar, and Ximing Cai, et al., "Virtual Groundwater Transfers from Overexploited Aquifers in the United States," *Proceedings of the National Academies of Science*, vol. 112, no. 28 (July 14, 2015), http://www.pnas.org/content/112/28/8561.full.pdf.

[67] Ibid.

Figure 16. Farm Bill Irrigation BMPs Funding by Watershed, FY2009-FY2014

Cumulative funding over six years in nominal dollars



Source: CRS from data supplied by USDA-Natural Resource Conservation Service (NRCS) on June 16, 2015.

Notes: The map displays information by hydrologic unit code (HUC). Although some HUCs cross national boundaries into Canada and Mexico, federal funding to producers implementing BMPs is for the United States only. For a state-by-state breakdown of farm bill irrigation BMPs funding, see **Appendix C**.

- *Environmental Quality Incentives Program (EQIP).*[68] EQIP awards financial and technical assistance contracts for several irrigation BMPs with payments based on estimated implementation costs. Conservation Activity Plans (CAPs) and Conservation Innovation Grants (CIG) are also funded through EQIP. Irrigation water management plans are funded through CAPs, while Conservation Innovation Grants are used to fund projects like local or regional irrigation conservation programs.[69]
- *Conservation Stewardship Program (CSP).*[70] CSP also provides funding for irrigation BMPs, awarding payments based on conservation performance, as opposed to flat payments based on rental rates or implementation costs. While CSP funds traditional conservation practices like crop rotation, it also funds the

[68] For a list of irrigation BMPs funded through EQIP along with their practice codes, see **Appendix B**.

[69] For an example of how Conservation Innovation Grants are used to promote irrigation conservation, see Quenna Terry, "Texas Water District, USDA Partner to Show Producers Way to Use Water Wisely," *USDA Blog* (May 14, 2015), http://blogs.usda.gov/2015/05/14/texas-water-district-usda-partner-to-show-producers-way-to-use-water-wisely/

[70] For a list of irrigation BMPs funded through CSP along with their practice codes, see **Appendix B**.

implementation of precision technologies, including regional weather networks for irrigation scheduling, irrigation system automation, and remote monitoring notification of irrigation pumping plants.

- *Agricultural Management Assistance (AMA).* AMA funds several of the same irrigation BMPs that are funded by EQIP. Funding through AMA, however, is limited to 16 states where participation in the Federal Crop Insurance program is historically low.[71]

Technical Assistance

USDA provides technical assistance for the adoption of irrigation technologies through a number of agencies and programs. The financial assistance programs (described in the previous section) all include an element of technical assistance associated with receiving program funds. USDA research efforts (described in the next section) provide the scientific foundation on which technical assistance is provided. While only one program is listed below, a number of other agencies and programs include elements of technical assistance.

- *Conservation Technical Assistance (CTA).* CTA helps irrigators adopt conservation plans by offering technical assistance through a national network of locally-based conservationists. While CTA does not offer financial assistance, the conservation plans developed through CTA can be used as a springboard to qualify for financial assistance programs. CTA is available to farmers and the groups that support them, including state and local government units, citizen groups, and professional consultants, and funded over $5.7 billion in technical assistance between 2003 and 2013.[72]

Research

USDA provides information resources to irrigators through the Agricultural Research Service (ARS), Economic Research Service (ERS), and National Institute of Food and Agriculture (NIFA).

- *Agricultural Research Service (ARS)*. ARS is the primary agricultural research organization in USDA and performs scientific research related to irrigation BMPs. Recent ARS irrigation studies focused on improving irrigation management, optimizing irrigation scheduling, and managing deficit irrigation.[73]
- *Economic Research Service (ERS)*. ERS is the primary source of economic information in USDA and conducts economic and policy studies on agricultural issues, including irrigation water use and conservation. Recent ERS studies have looked at characteristics of irrigated farms in 17 western states and water conservation trends in irrigated agriculture across the United States.[74]

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[71] Eligible states for AMA include Connecticut, Delaware, Hawaii, Maine, Maryland, Massachusetts, Nevada, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Utah, Vermont, West Virginia, and Wyoming.

[72] USDA, NRCS, "CTA Cumulative Technical Assistance Funds FY 2003-2013," (April 2014), http://www.nrcs.usda.gov/Internet/FSE_MEDIA/stelprdb1251317.png.

[73] A comprehensive list of ARS irrigation projects can be found by searching "irrigation" at http://www.ars.usda.gov/research/projects.htm.

[74] ERS products on irrigation can be accessed at http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx.

- *National Institute of Food and Agriculture (NIFA).* NIFA administers federal funding to support agriculture related science and research, primarily at state universities. NIFA-funded grant programs related to irrigation include the Agriculture and Food Research Initiative (AFRI) Water for Agriculture Challenge Area and the National Water Quality Program (NWQP).[75]

Monitoring/Reporting

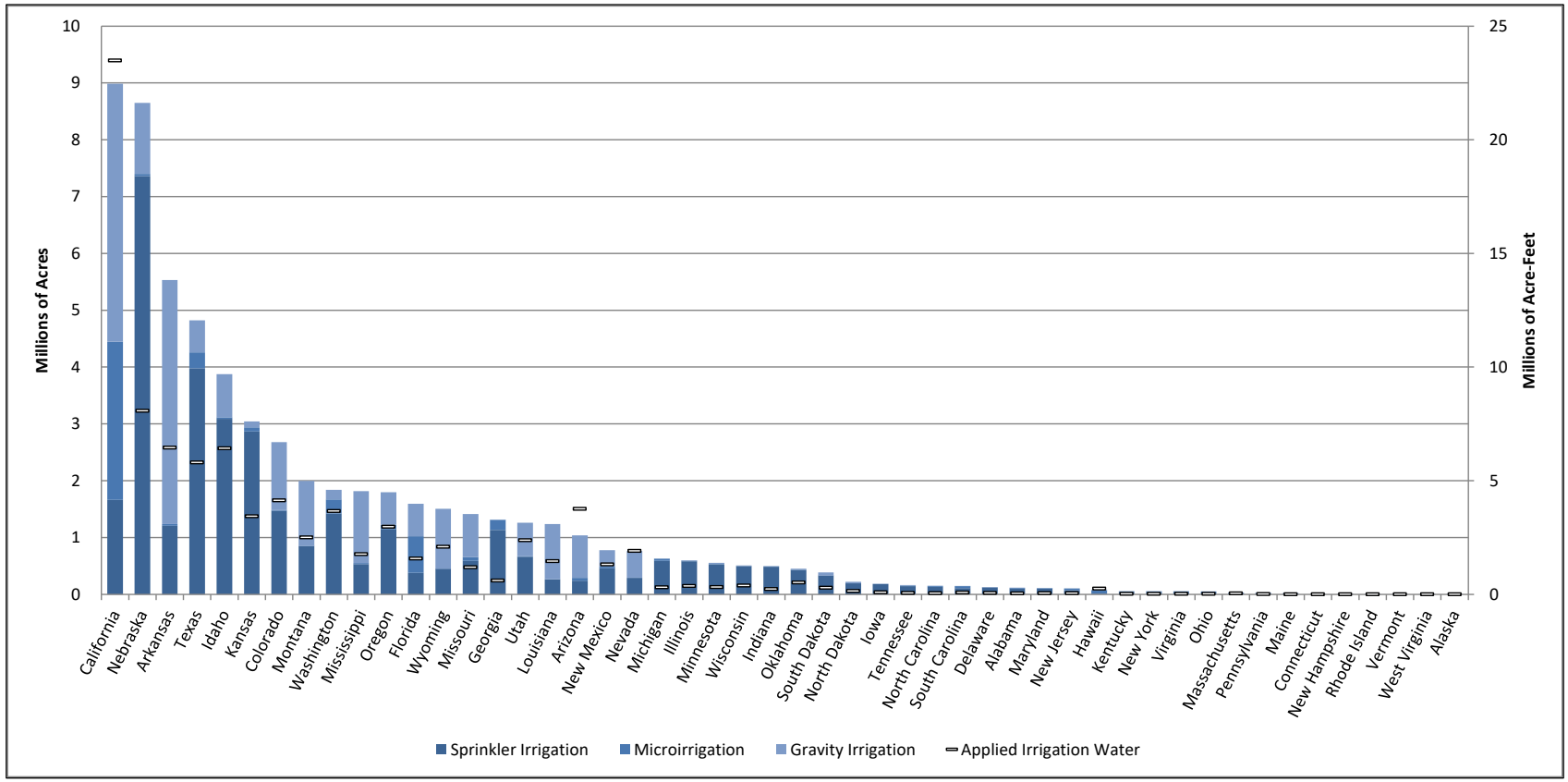
Few irrigation-related monitoring and reporting efforts occur at the national level. The National Agricultural Statistics Service (NASS) and U.S. Geological Survey (USGS) provide the most complete national picture of irrigation water use but, due to differing methodologies and reporting schedules, cannot be directly compared.

- *National Agricultural Statistics Service (NASS)*. NASS compiles data on the United States agriculture industry through conducting surveys of producers. NASS produces the Farm and Ranch Irrigation Survey every five years (i.e., 2003, 2008, 2013), which serves as a national assessment of irrigated agriculture in the United States.
- *United States Geological Survey (USGS)*. USGS, in the Department of the Interior, produces an assessment of water use in the United States that is typically released every five years (i.e., 2000, 2005, 2010). This water use assessment evaluates trends in major water use categories including irrigation.

[75] For more information on NIFA's focus on water and water programs, see http://nifa.usda.gov/topic/water.

Appendix A. Irrigation Technologies and Water Use

Figure A-1. Irrigation Technologies and Water Use by State, 2013



Source: CRS from USDA, NASS, *2013 Farm and Ranch Irrigation Survey*, Tables 6 and 28, http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

Appendix B. Practice Codes and Definitions for Irrigation BMPs[76]

Environmental Quality Incentives Program (EQIP). These irrigation practices qualify for funding from the NRCS EQIP.

Sprinkler System—Code 442. A sprinkler system is a general term to describe the most common types of pressure irrigation systems like center pivot, side roll, and linear move tower irrigation. These systems spray water into the air through a sprinkler or nozzle over a crop area to provide adequate soil moisture for crops. Sprinkler systems are also used for crop cooling, frost protection, and dust control.

Irrigation System, Microirrigation—Code 441. Frequent low-pressure, low-volume irrigation applied near the roots of the plant through above- or below-ground tubing.

Irrigation Pipeline—Code 430. A pipeline is built to convey water to an irrigation system or storage area in a way that minimizes water loss.

Pumping Plant—Code 533. A pumping plant delivers water at a predefined pressure and flow rate based on a conservation need and requires an on-site energy source.

Irrigation Land Leveling—Code 464. The reshaping of land based on an engineered plan to increase surface irrigation efficiency, reduce erosion, prevent water logging of soil or crops, and prevent water quality loss.

Water Well—Code 642. A water well is used to extract groundwater from an aquifer. Possible interference with neighboring wells, groundwater overdraft, and impacts on cultural, archaeological, or scientific resources near the site should be evaluated in planning.

Structure for Water Control—Code 587. A structure that is used to convey water, regulate direction or flow rates, retain a specified water surface elevation, or measure water. These structures include flashboard risers, check dams, division boxes, water measurement devices, and pipe drop inlets.

Irrigation Reservoir—Code 436. A reservoir is a water storage structure that is built to provide a reliable water supply for irrigation. Irrigation reservoirs may be built by constructing a dam, embankment, pit, or tank.

Irrigation Water Management—Code 436. Planning efficient volume frequency and application rate of irrigation to manage soil moisture and promote plant growth. Irrigation scheduling is the most important element of water management.

Irrigation System, Surface and Subsurface—Code 443. An irrigation system involving earthwork, multi-outlet pipelines, and water-control structures to convey water to irrigated areas while reducing water loss, erosion, energy use, and water quality impairment.

Irrigation Ditch Lining—Code 428. A lining made of impervious material that is installed in a canal, lateral, or ditch, to improve water conveyance, reduce water loss and energy costs, prevent erosion, and maintain water quality.

[76] Practice codes refer to an NRCS numbering system and are included for reference. For more detailed information on each practice standard, refer to the conservation practice information sheet at http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849.

Irrigation System, Tailwater Recovery—Code 447. Facilities built to capture irrigation runoff that can be conveyed back into the irrigation system for reuse to conserve water and improve off-site water quality.

Dam, Diversion—Code 348. A diversion dam is constructed to divert surface water from a watercourse or stream into another watercourse like an irrigation canal.

Irrigation Field Ditch—Code 388. A ditch built from earth materials to convey water from a primary source to irrigation areas.

Irrigation Canal or Lateral—Code 320. A permanent channel created to efficiently deliver water from water source to irrigation areas. The canal or lateral must be lined where soil is of moderately rapid to very rapid permeability.

Irrigation Water Management Plan—Code 118. An irrigation water management plan is implemented to achieve irrigation efficiency to optimize crop yield, reduce water contamination, minimize soil erosion, manage soil salinity, and reduce energy use.

Transition from Irrigation to Dryland Farming and Ranching – Code 134. Dryland farming is a method of production under limited precipitation in areas that are typically under severe resource constraints. This method focuses on crop yield sustainability and water conservation.

Conservation Stewardship Program (CSP). These irrigation practices are eligible for funding from the NRCS CSP.

Regional Weather Networks for Irrigation Scheduling—WQT07. Information from the regional weather networks are used to track crop evapotranspiration to plan irrigation scheduling. By combining this information with precipitation and soil moisture data, an accurate irrigation schedule can be established.

Irrigation System Automation—WQT01. This type of system uses GPS-guided variable rate irrigation or other similar technologies to adjust water application rates based on variable field conditions like soil, topography, and crop type.

Irrigation Pumping Plant Evaluation—WQT03. This enhancement evaluates the energy efficiency of a pumping plant and determines modifications that can reduce energy consumption and water use.

Remote Monitoring Notification of Irrigation Pumping Plants—WQT05. A remote monitoring notification system wirelessly transfers real-time information to the operator of a pumping plant on any changes in the operating status of the irrigation system. This information is used to prioritize field visits for required maintenance and adjustments.

Decrease Irrigation Water Quantity or Conversion to Nonirrigated Crop Production—WQT08. This practice requires an irrigator to reduce or eliminate irrigation for the purpose of conserving water supplies and reducing energy use where irrigation water is pumped.

Mulching for Moisture Conservation (Used in 2010 and 2011)—WQT02. This enhancement uses fibrous mulch to reduce irrigation evaporation loss from the soil surface.

High-Level Irrigation Water Management—WQT09. High-level irrigation water management reduces water and energy use through irrigation scheduling based on information acquired through remote soil moisture sensors.

Center Pivot Irrigation System End Gun Removal—WQT10. This enhancement requires the removal of an end gun sprinkler that is placed at the outer edge of a center pivot system to expand

irrigation coverage. This practice will improve water conservation and increase irrigation efficiency.

Low Energy Precision Application Irrigation—WQT11. This enhancement converts standard center pivot irrigation systems to low energy precision application (LEPA) irrigation systems. LEPA systems apply water directly into furrows through nozzles placed close to the soil surface to reduce evaporation losses and energy consumption.

Computerized Hole Selection for Poly-Pipe—WQT12. Computer software is used to optimize hole sizes for poly-pipe used in furrow irrigation to decrease water quantity applied per season and irrigation runoff.

Intermittent Flooding of Rice Fields—WQT13. This irrigation technique allows rice fields to "dry down" to a saturated soil condition in between flooding cycles of rice fields.

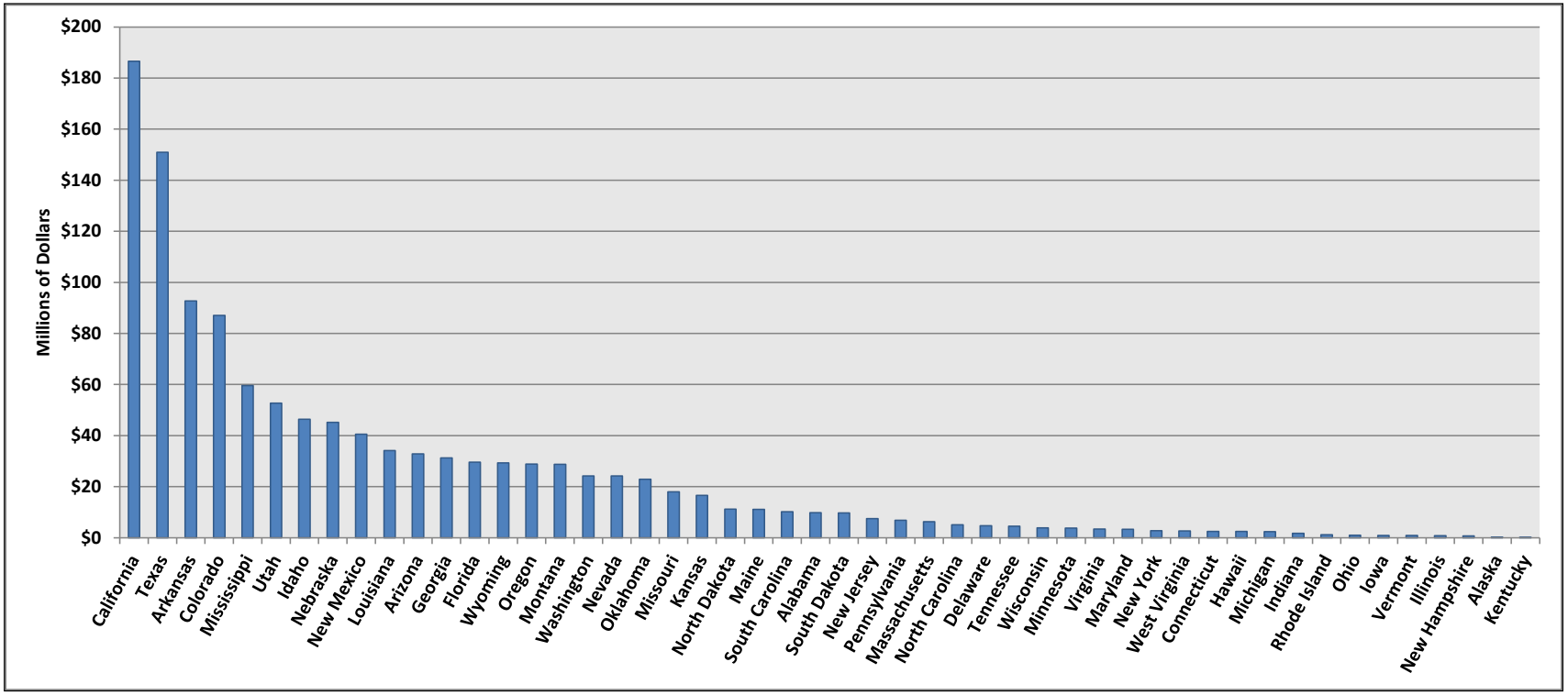
Resource Conserving Crop Rotation (RRCR)—CCR99. This is a crop rotation that includes at least one resource-conserving crop like a perennial grass to reduce erosion, improve soil fertility, interfere with pest cycles, and reduce soil moisture depletion and water application.

Improved Resource Conserving Crop Rotation—CCR98. This is an enhancement of the Resource Conserving Crop Rotation listed above to further reduce erosion, improve soil fertility, interfere with pest cycles, and reduce soil moisture depletion and water application.

Appendix C. Irrigation BMPs Funding

Figure C-1. Farm Bill Irrigation BMPs Funding by State, FY2009-FY2014

Cumulative funding over six-year time period in nominal dollars



Source: CRS from data supplied by USDA, NRCS on June 16, 2015.

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