2013

Agricultural Irrigation

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FOOD, AGRICULTURE, AND ENVIRONMENTAL LAW

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Chapter 4
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Irrigation is a key element in any analysis of domestic and global agriculture. It has been a central part of agriculture for millennia, and is known to have been practiced by indigenous peoples in the American Southwest as early as 100 B.C.[1] Ruins of early irrigation canals are still visible in the vicinity of the Gila and Salt Rivers in what is now Arizona; the canals served to irrigate lands in the Pima and Papagos pueblos.[2] Similarly, in what is now New Mexico, the Indians in the Rio Grande Valley irrigated their farms long before the Spaniards arrived at the end of the 15th century.[3]

Despite these and numerous other efforts throughout the Southwest, large-scale irrigation was not successful until the Mormons entered the Salt Lake Valley in Utah in 1847.[4] By 1850, 926 Utah farms involving a total of 16,133 acres were under irrigation.[5] By 1860 there were 77,219 irrigated acres of farmland growing crops that were vital to the survival of the community.[6] The Mormon achievement is the first large agricultural economy in the West dependent entirely upon artificial irrigation.[7] The central engineering method was the efficient and sustainable diversion and conveyance of canyon streams to distant valley farmlands.[8] The Mormon success provided the model from which the first generations of irrigation in the United States grew.[9]

Irrigation is today a feature of agriculture in all 50 American states.[10] Over 55 million acres are irrigated, and nearly 50 million of those acres are on farms of 200 acres or more. Just under 30 million of those acres are on farms with more than 1,000 acres.[11] In 1997, the West held 78% of the country's irrigated land, but recent trends forecast faster growth in the East.[12] From 1987 to 1997, irrigated land increased by 14% in the West, and 38% in the East.[13] Substantial increases in irrigation must be anticipated as land prices escalate, the total amount of land available for agriculture diminishes, demand for all crops increases, costs of irrigation infrastructure are lowered, and financial capital concentrates.[14]

When done well, irrigation has only minor environmental impacts.[15] It can conserve water, allow full utilization of prime soils, increase productivity of existing tilled acres, enhance the production of essential human foods, and provide resiliency during periods of drought.[16] Irrigation has the potential to help agriculture shift toward sustainability—using resources to serve both present and future generations. That this

1. Design and Operation of Farm Irrigation Systems 8 (G.J. Hoffman et al. eds., 2d ed., 2007) [hereinafter Design].
2. National Research Council, Comm. on the Future of Irrigation, A New Era for Irrigation 9 (Nat'l Academy Press, 1996) and J.L. Sax et al., Legal Control of Water Resources 326-27 (4th ed. 2006).
3. *See generally* S. Crawford, Mayordomo: Chronicle of an Acequia in Northern New Mexico (1988).
4. Sax et al., *supra* note 2, at 327.
5. United States Seventh Census, 1850, 1006 (1853).
6. United States Eighth Census, 1860, Agriculture, 180 (1864).
7. *Id.*
8. *Id.*
9. *Id.*
10. Charles A. Job, Groundwater Economics 203 (2010).
11. U.S. Dep't. of Agric., National Agricultural Statistics Service, *2008 Farm and Ranch Irrigation Survey, in* The Census of Agriculture (2008).
12. Job, Groundwater Economics, *supra* note 10, at 203.
13. *Id.*
14. Lawrence J. MacDonnell, From Reclamation to Sustainability: Water, Agriculture, and the Environment in the American West 1-9 (1999).
15. *Id.*
16. *Id.*

chapter is discussing environmental problems of irrigation, however, simply reflects what is well known—irrigation is not always, or even regularly, done well. Or, to state things in a more positive way: we are still learning how to irrigate our crops in an environmentally beneficial manner.

As often occurs with natural resources management, the potential for harm to the environment became apparent as the result of a specific disaster, and for irrigation that case was provided by the Kesterton Wildlife Refuge in California's San Joaquin Valley. There, from 1971 to 1978, man-made ponds were supplied entirely by fresh water. As the result of operational changes, the supply by 1982 was entirely irrigation drainage water.[17] In 1982, it was observed that the irrigation drainage was increasing selenium concentrations in the refuge's ponds, resulting in reproductive failure and death in some species of the aquatic life, including waterfowl.[18] The pollution at Kesterton was the result of both natural and human factors.[19] Selenium is found naturally in soils like many salts. Intensified irrigation with the installation of subsurface drains without consideration of the effects of the content and disposal of drainage water led to serious water quality impacts.[20] As summarized in a subsequent report of the National Research Council: "The underlying issue is clear: irrigation, like many other uses of water, degrades water quality for water users. The contaminant of concern and the severity of impacts may vary, but the phenomenon of irrigation-induced water quality contamination can no longer be ignored."[21]

As a caveat, it should be said that any thoughtful consideration of surface water irrigation as practiced in the United States requires recognition that it is not simply the application of water to plants; it is the system that provides the basis for an economy, a way of life, and which gave rise to the settlement of the American West.[22] Irrigation has its own distinct social, economic, political, and agronomic history, and is often the result of generations of extraordinary human ingenuity and perseverance. Many of the political and social institutions now familiar in farm country—irrigation districts in particular—are the result of efforts to develop irrigation agriculture. Much of this history and achievement is lost to view in our urbanized society, but it is unwise to discuss irrigation without taking this special history into account. Many of the most visible controversies in irrigation country may have been, in part, a result of failure to recognize this special history and culture.[23]

A. Irrigation in Practice

To understand how irrigation impacts the environment today, it is necessary, first, to appreciate how irrigation practices have evolved over the past century. It is important also to understand the purposes of field drainage and the engineering techniques used.

1. Background

Early irrigation works in the United States were rudimentary. Small diversion structures were built up at the side of flowing streams, allowing water to spill into ditches through which water flowed by gravity to fields at lower elevations.[24] Incrementally, such irrigation works evolved into interrelated projects requiring elaborate ditch systems and construction of enhanced storage at the point of diversion.[25] The early surface system had complete access to the streams—there were few conflicting claimants for the water—and, as a result, tended to be wasteful, losing vast amounts to seepage and evaporation, problems that persist to this day.[26] From this early experience, it became apparent that successful surface water irrigation requires large capital expenditures as well as institutions by which to organize irrigating landowners.

17. National Research Council, Comm. on Irrigation-Induced Water Quality Problems, *Irrigation-Induced Water Quality Problems: What Can Be Learned From the San Joaquin Valley Experience* 1 (1989).
18. *Id.*
19. *Id.*
20. National Research Council, *supra* note 17.
21. *Id.* at 2.
22. National Research Council, Comm. on the Future of Irrigation, *A New Era for Irrigation* 2 (1996).
23. *See* A. Dan Tarlock & Holly D. Doremus, *Fish, Farms, and the Clash of Cultures in the Klamath Basin*, 30 Ecol. L.Q. 279 (2003).
24. MacDonnell, *supra* note 14, at 1-9.
25. *Id.*
26. *Id.*

Three significant landmarks now appear in the history of irrigation development in the United States. The first of these is judicial sanction of California's Wright Act in 1896.[27] Physically and economically, it is usually unfeasible for an independent farm enterprise to construct large-scale surface irrigation without the cooperation of surrounding landowners. In recognition of this, all state legislatures have enacted enabling laws for special districts that provide generous police and financing powers to supplement the land development enterprise. Today, rural America is governed by thousands of local government units that function apart from the standard county, municipal, and school district entities.[28] In regions where surface water irrigation prevails, these districts are quite often the most significant units of local government.[29]

The consistent theme in the slow development of western irrigation is the lack of capital. Some early mutual companies met with success, especially in Utah, but as a general matter few privately owned water companies were able to amass capital sufficient to construct irrigation on a meaningful scale.[30] The Wright Act changed that and became the model for rural special districts across the land.[31] The Act empowered irrigation districts to levy property assessments, issue bonds, and be controlled by local landowners.[32] The key, however, was that the Act gave districts the power to include unwilling landowners within the district boundaries and to exercise the power of eminent domain.[33] Landowners resented being forced into districts against their will, and it took a strong opinion from the U.S. Supreme Court to settle the matter.[34] Governmental in form, and exercising governmental powers, special districts serve predominantly private purposes. This fact was recognized by Justice Potter Stewart in 1981, when he wrote that "though the state legislature has allowed water districts to become nominal public entities in order to obtain inexpensive financing, the districts remain essential business enterprises, created and chiefly benefiting a specific group of landowners."[35]

The second landmark is passage in 1902 of the federal reclamation law, usually referred to as the Newlands Act, and also known as the Reclamation Act.[36] Beginning in the 1890s, western farmers—now more stoutly organized in their special districts—encouraged the federal government to become involved in the delivery of water to farmers. After years of failed experiments with half-measures, Congress enacted the Newlands Act, under which the federal government itself would construct irrigation projects and deliver water to western farmers.[37] The extent of the impact of this program is summarized accurately in a recent volume on water law:

> Under the guidance of the Bureau of Reclamation, . . . the federal reclamation program has radically transformed the West over the last century. The Bureau has built over 600 dams, 16,000 miles of canals and aqueducts, 280 miles of tunnels, 37,000 miles of laterals, 50 hydroelectric generators, and 140 pumping stations. Through local water districts, the Bureau currently supplies water to roughly 10 million acres of cropland—about half of all the land irrigated by surface water in the West—as well as to 30 million domestic users. The federal reclamation program, however, has generated considerable criticism. Reclamation water is heavily subsidized by federal taxpayers and, in many parts of the West, goes to large farmers who often have enjoyed other federal farm subsidies. Few Bureau projects have ever paid for themselves, even if you ignore the interest that the federal government absorbs on every project. Numerous Bureau projects, moreover, have caused sizeable environmental damage.[38]

The third major development was the application of well-drilling technology to groundwater pumping. Prior to the 1940s, the technology was crude and incapable of developing flows of water sufficient to

27. *Public Water Supply Organizations, in* 2 WATER AND WATER RIGHTS §27 (R. Beck & A. Kelley eds., 2011 edition).
28. *See, e.g.,* S.N. Bretsen & P.J. Hill, *Irrigation Institutions in the American West,* 25 U.C.L.A. J. ENVT'L L. & POL'Y 283 (2006) and Harriet M. Hageman, *Irrigation Districts as Public Corporations,* 32 WYO. LAW. 16 (2009).
29. *Id.*
30. John H. Davidson, *South Dakota's Special Water Districts—An Introduction,* 36 S.D. L. REV. 499, 539-49 (1991).
31. *Id.*
32. *Id.*
33. *Id.*
34. Fallbrook Irrigation Dist. v. Bradley, 164 U.S. 112 (1896). The Court held that inclusion and taxation of nonirrigable lands with an adequate water supply and within incorporated cities did not violate the Due Process Clause.
35. Ball v. James, 451 U.S. 355 (1981).
36. MACDONNELL, *supra* note 14, at 143-44.
37. 32 Stat. 388.
38. SAX ET AL., *supra* note 2, at 687-88. A.K. Kelley, *Federal Reclamation Law,* in 4 WATER AND WATER RIGHTS §41.02 (Robert Beck ed., Repl. Vol. 2011).

support widespread use in farm fields.[39] In the 1940s, well drillers began using drill bits similar to those employed in oil fields, resulting in wider holes.[40] During the same period, irrigators acquired high-speed turbine pumps, which could push the water up the well in large quantities.[41] With these tools in hand, development of groundwater sources for irrigation expanded rapidly, first in the West and moving steadily eastward through the plains to the East Coast.[42] The ability to pump water at the site of use, combined with the development of efficient center-pivot sprinkler systems, allowed for irrigation without the need for complex surface water systems of ditches, laterals, and canals. In 2003, there were 401,193 irrigation wells that were in use in the United States.[43]

2. *Field Drainage: Purposes*

> It has been said that every irrigation project eventually becomes a drainage project. Ditches for the collection of waste water and its redistribution to other users, and for the drainage of what would otherwise become seeped and boggy lands, are commonly constructed as part of modern projects, or as additions to older projects, by drainage districts or by the irrigation district that distribute the water.[44]

As there is a recognized hydrologic cycle, there is a parallel irrigation cycle. Irrigation water passes through the soil-crop system, and drainage carries off salts, nutrients, pesticides, and trace elements.[45] Much of the irrigation water that enters the plants is transpired back into the atmosphere.[46] A smaller portion is incorporated into plant tissues, and the remainder leaves the soil-crop system by leaching, runoff, seepage, or subsurface drainage.[47] Because a significant portion of all soils under irrigation are subject to "waterlogging" of soils, artificial drainage is necessary.[48] Irrigation is short-lived in the absence of adequate drainage.[49] California alone has millions of miles of agricultural drains.[50]

Because successful land drainage is an essential component of irrigation, it is described here in some detail. It should be noted that the drainage techniques described here apply equally to nonirrigated field agriculture as well.

Agricultural drainage has been defined as the art and science of removing water from land to enhance agricultural operations.[51] One engineering treatise states: "The main objective of agricultural land drainage is to remove excess water in order to improve the profitability of farming the land."[52] Another definition states: "The objective of drainage in agriculture is to create between the soil surface and the water table a partially saturated zone of optimum quality and extent for exploitation by plants and for the management of the soil and crops by the farmer."[53]

There are several incentives for constructing drainage structures on and beneath agricultural land. First, some soils, either due to their structure or their topography, are waterlogged during a portion of the growing season. In this condition, plant roots do not receive adequate oxygen, soil is compacted, and crop growth is hindered; drainage can correct this problem.[54]

Second, constructed drainage may lengthen the crop growing season on a particular farm.[55] When fields are slow to lose the moisture that builds up after the spring thaw or heavy rains, the farmer must delay

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39. JOB, GROUNDWATER ECONOMICS, *supra* note 10, at 204.
40. *Id.*
41. *Id.* at 204-05.
42. *Id.*
43. *Id.* at 204.
44. FRANK J. TRELEASE & GEORGE A. GOULD, WATER LAW CASES AND MATERIALS 232-33 (4th ed. 1986).
45. Nat'l Research Council, *supra* note 17, at 3.
46. *Id.*
47. Nat'l Research Council, Committee on Long-Range Soil and Water Conservation, *Soil and Water Quality: An Agenda for Agriculture* 57 (1993).
48. Nat'l Research Council, *supra* note 17, at 3-4.
49. *Id.* at 364. Western Water Policy Review Commission, *Water in the West: Challenge for the Next Century* 2-31-32 (June 1998).
50. L.N. Smith & L.J. Harlow, *Regulation of Nonpoint Source Agricultural Discharge in California*, 26 A.B.A., NAT'L RES. & ENV'T 28 (2011).
51. L.K. SMEDEMA & D.W. RYCROFT, LAND DRAINAGE: PLANNING AND DESIGN OF AGRICULTURAL DRAINAGE SYSTEMS 39 (1984).
52. DRAINAGE FOR AGRICULTURE 311 (J. Van Schilfgaarde ed., 1974). *See also* G.O. SCHWAB ET AL., SOIL AND WATER CONSERVATION ENGINEERING 1 (3d ed. 1981).
53. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 311.
54. FIELD DRAINAGE: PRINCIPLES AND PRACTICE 21 (D. Castle et al. eds., 1985).
55. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 7.

planting, weed control, harvesting, and other field work.[56] If the land is seeded to pasture, there are delays in turning livestock in; drainage can correct this problem.[57]

Third, drainage allows farmers to bring into production land that nature has otherwise claimed as swamp, wetland, slough, or marsh, in the case of humid lands (and arid valley floors in the case of irrigation).[58] Despite the resulting loss to water conservation and wildlife habitat, the opportunity to "make land" is an inviting prospect for the landowner, particularly when agricultural land values are high.[59]

Fourth, drainage allows farmers to improve the productivity of land already in production. For example, land that is naturally wet, and has supported only grass, may, after drainage, be brought into row-crop production.[60]

Fifth, agricultural drainage pipe systems are an essential engineering feature of most organized irrigation projects. Land under irrigation is exposed to the risk of waterlogging with resultant leaching of chemical salts into the plant root zone.[61] By placing drainage pipes beneath the root zone, the risk of salinity is reduced. Salinity control may also be an objective of drainage on farms not served by irrigation.[62]

The farmer who drains land is influencing the hydrologic cycle by accelerating the flow of excess water from the land before it damages the soil structure and affects the crop.[63] This practice is well accepted and is closely associated with good land husbandry.[64] The economic incentive for drainage by the individual landowner is compelling, for it presents an opportunity, at relatively low cost, to increase the production of a capital asset that is already owned.[65] Despite the substantial acreage of land already drained in this country, the combination of intense economic pressure on farmers to improve production in order to achieve profitability, as well as the ever-improving efficiency and diminishing cost of drainage technology, creates an economic environment in which a rapid expansion of drainage is under way.[66] Technical engineering sources hold that excess water continues to be a "major problem" on 25% of U.S. cropland.[67]

Moreover, as more of America's productive farmland accumulates in the hands of larger operating entities, demands for profit accelerate the expansion of agricultural land drainage.[68] The potential for problems is worldwide, as so many countries are feeling pressure to bring new land into production in order to achieve domestic food requirements and compete for export markets.[69]

3. *Field Drainage: Techniques*

Taken in the aggregate, the engineering features of drainage are far from simple, and represent extensive and precise interference with natural hydrologic systems. Their purpose is to move water steadily from where it is not wanted—farm fields—to watercourses that will carry it away. A good portion of this water would, under natural conditions, remain in the soil and never reach a watercourse. This is particularly true in the Great Plains where, although annual rainfall is not great, much of the topography is such that soils retain the greatest part of precipitation rather than lose it to streams through runoff.[70] Hence, agricultural field drainage not only speeds the flow of water to rivers and streams, it also augments flows in those rivers and streams well beyond natural levels. Typical drainage is not unlike a municipal sewer collector system. A large number of small pipes carry flows to larger conduits where the waters are gathered for disposal. The waters are collected on the surface and the subsurface of the land. Surface water passes rather quickly over

56. *Id.*
57. *Id.*
58. Field Drainage: Principles and Practice, *supra* note 54, at 20; Schwab et al., *supra* note 52, at 1.
59. *Id.*
60. Field Drainage: Principles and Practice, *supra* note 54, at 20.
61. Drainage for Agriculture, *supra* note 52.
62. *Id.*
63. Field Drainage: Principles and Practice, *supra* note 54, at 69.
64. *See, e.g.*, Gross v. Connecticut Mutual Life Insurance Company, 361 N.W.2d 259 (S.D. 1985).
65. *Id.*
66. Jon R. Luoma, *Twilight in Pothole Country*, Audubon, Sept. 1985, at 68, 75.
67. Schwab et al., *supra* note 52, at 5.
68. Drainage for Agriculture, *supra* note 52, at xv.
69. *Id.*
70. *Id.*

the soil without infiltrating it. As it does so, it picks up suspended and soluble material. Subsurface water moves slowly through the soil, and in so doing, leaches chemicals from it.[71]

Typical agricultural field drainage is accomplished by a combination of field shaping and leveling, as well as surface and subsurface pipes and drains. Each system will reflect the topography, climate, soil type, cropping pattern, and economics of a particular farm.[72] Surface ditches and pipe drains, in combination with open channels, are the most frequent methods used.[73] Because drainage rarely honors surveyor's lines, it is customary for neighboring landowners to cooperate in developing drainage, and large special municipal drainage districts are commonplace.[74]

Subsurface drains are placed in the ground directly below the root zone. They may be spaced as closely as every four feet but typically are found in spacings of more than 20 to 30 feet.[75] The pipe drains may be concrete, burned clay tile, corrugated plastic tubing, or other perforated conduit.[76] Corrugated steel is used where there is a heavy soil load or unstable soils, and to provide a stable outlet into open ditches.[77]

Installation is by a variety of trenching methods. Recent advances in the technology of installation have made field drainage more available than ever before.[78] Rolled plastic pipe can now be buried on the move by trenching "pipe trains," which simultaneously dig the trench, install the pipe at the correct angle, and cover it.[79] Lateral drains are intended to receive water directly from the soil and pass it on to main lines, which gather the flows. Main lines can be either surface or subsurface conduits.[80]

The patterns for the layout of subsurface drains are usually described in four categories: (1) the herringbone, used in areas that have a concave surface or a narrow draw with the land sloping to it from either direction; (2) the gridiron, which is similar to the herringbone except the laterals enter only from one side; (3) the cutoff or interceptor, which is normally placed over the upper edge of a wet area; and (4) the random design, used in smaller isolated areas.[81] The outlets for subsurface pipe drains are usually operated on gravity principles although pump drains are frequently used.[82]

The benefits of subsurface drains are that they do not interfere with farming, make more efficient those soils that do not drain naturally, aerate the soil, remove salts and other toxics from the root zone, and reduce surface runoff.[83]

Surface drains (open ditches) are an essential complement to subsurface drainage.[84] Open channels provide outlets for tile and surface drains and also carry off surface waters.[85] They are generally earth-lined and drain much larger areas.[86] The open drain is excellent for rapid removal of large quantities of water, and also enjoys great cost advantages over covered drains.[87]

A common use of the open channel is to connect wetlands to drains so that the wetland areas can be farmed. So used, the channel will rarely be more than one or two yards deep, and may be so shaped that it can be farmed or, at least, allow for the easy passage of farm vehicles. From an engineering standpoint, a properly designed open ditch should provide a velocity of flow that does not allow scouring or sedimentation; this requires sufficient capacity, stable side slopes, and correct hydraulic grade.[88] Channels, of course, may require substantial structures of concrete or other materials, the purpose of which is channel stabilization.[89]

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71. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 490.
72. *Id.* at 93.
73. SCHWAB ET AL., *supra* note 52, at 8.
74. *Supra* note 28.
75. SCHWAB ET AL., *supra* note 52, at 8.
76. *Id.*
77. *Id.* at 318-19.
78. *Id.* at 348-50.
79. *Id.*
80. *Id.* at 319.
81. *Id.* at 321-22. *See also* SMEDEMA & RYCROFT, LAND DRAINAGE, *supra* note 51, at 50-95.
82. SCHWAB ET AL., *supra* note 52, at 322-23.
83. *Id.* at 314.
84. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 101.
85. SCHWAB ET AL., *supra* note 52, at 290.
86. *Id.*
87. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 99.
88. *Id.*
89. *Id.*

Earth embankments and farm ponds are sometimes used as part of surface land drainage schemes. They normally serve to hold back water so that it may be used for other purposes such as stock watering or irrigation.[90] Additionally, they serve the advantageous role of keeping waters from main channels where it can contribute to flooding.[91]

Random field drains are best suited for draining scattered depressions or potholes. The location and direction of these drains will be dictated largely by the topography. Side slopes are generally as flat as possible so that tillage operations can be performed through the channels. Erosion in the channel is generally not a problem because the grades are flat. Spoil from the channel should be spread or moved into the depression to reduce the depth of the drain.

Where fields are flat with slopes less than 2%, a system of parallel drains is often used. Where dead furrows are left by plowing lands at the same location for several years, the drainage system is known as "bedding."

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Drainage has, of course, been practiced for more than 2,000 years. Discussions of it can be found in Roman history and that of most other significant civilizations.[92] In England, a royal charter was granted in 1252 to a board of commissioners that sat as a court to maintain drainage, carry out drainage improvements, and resolve land drainage disputes.[93] But it is only since the second half of the 19th century—with the development of drainage engineering theory and manufactured drain tile, combined with extravagant public subsidies—that it has become commonplace. Moreover, with the importance of irrigation in the American West and the growth of irrigation in the eastern United States as well, drainage is of increasing significance everywhere. Observers of American farming are keenly aware that drainage engineering programs are an integral part of most successful farms, and that successful farming regions will inevitably boast of many organized irrigation and drainage districts. The 1969 agricultural census indicated that organized municipal drainage projects provided drainage over 90 million acres of land.[94] Landowners invested in drainage systems on over 29 million acres of farmland from 1975 to 1977.[95] For those same years, owners of 24 million acres of farmland reported investing about $2.25 billion for drainage.[96] About 15% of all owners making drainage investments in the 1975-1977 period participated in some type of drainage district.[97] It is estimated that 54 million acres of land presently in agricultural production in the United States could be made more productive by the application of drainage practices. About two-thirds of the land yet to be drained is in the South.[98]

A continuing objective of drainage systems is to drain wetlands in order to bring new land into production. A recent report points out that even before 1920 nearly one-half-million acres of North Dakota wetlands had been drained, and they continue to be drained at the rate of 20,000 acres per year.[99] Minnesota, one of the states most blessed with surface water, has lost 90% of its natural wetlands to agricultural drainage.[100]

B. The Potential Environmental Effects of Agricultural Irrigation

Agricultural irrigation can have negative impacts on the environment, principally caused by runoff from farmlands and overpumping of groundwater. Runoff water carries sediments and chemicals into surrounding streams. Excessive pumping of groundwater can deplete the water table, lessen surface resources, and damage the ecosystems dependent on them.

90. DRAINAGE FOR AGRICULTURE, *supra* note 52, at 101.
91. *Id.*
92. *See generally* H.H. Wooten & L.A. Jones, *The History of Our Drainage Enterprises*, *in* U.S.D.A. WATER: THE YEARBOOK OF AGRICULTURE 478 (1955).
93. FIELD DRAINAGE: PRINCIPLES AND PRACTICE, *supra* note 54, at 222.
94. Douglas Lewis & Thomas McDonald, *Improving U.S. Farmland*, 482 U.S.D.A. Agricultural Information Bulletin (Nov. 1984).
95. *Id.*
96. *Id.*
97. *Id.*
98. *Id.*
99. *Id.*
100. *Id.*

1. *Runoff From Farm Fields*

Land cultivation is a major polluting activity that, among other things, increases the amount of soil erosion.[101] Water from farm fields is also the primary carrier of pollutants from farmland. Drainage water or irrigation return flows carry sediment and chemicals, changing the quality of the drainage water.[102]

All natural waters and soils contain chemical salts, which drainage water will collect and concentrate. Although the collection of salts in drainage water is most often associated with irrigation return flows where salts have the best chance to concentrate in evaporating desert water, this phenomenon is also associated with drainage of humid lands.[103] Thus, irrigation drainage in particular exacts an environmental price by degrading water quality along the disposal routes, and in closed basins it "can render the terminus biologically uninhabitable."[104] Where there are seasonal low stream flows, as in the arid West, pollution problems result because depleted stream flows are comprised mostly of irrigation runoff.[105]And it is reported that irrigation return flows are the most common source of pollution in national wildlife refuges.[106]

Sediment is the major nonpoint (unregulated) pollutant of American waters.[107] One effect of most drainage systems is to accelerate the flow of water during spring thaw or immediately following rainfall. Waters that would naturally be retained in fields or flow quite slowly toward watercourses are gathered rapidly and cast into watercourses. As flows accumulate in open channels, the soil is scoured, and sediment loads increased.[108] Soil particles in water not only indicate loss of soils by erosion, but they carry attached to them most chemicals found in the soils. Sediment directly damages waters, but these waters also carry nutrients and pesticides from fields. In the long term, it is the presence of fertilizers, agricultural chemicals, and trace materials attached to the sediment that make agricultural drainage a major source of water pollution.[109] Ironically, that which is a benefit in the field can cause problems when transmitted to surface and groundwater.

2. *Groundwater Pumping*

Groundwater is a principal source not only for irrigation but also for municipal and industrial use. The overall supply is vast—the largest source of freshwater—but its availability varies from place to place, depending upon the depth of the supply, geologic conditions, and the volume of water needed at a site.[110] Its availability at the place of use and its widespread availability mean that it is a resource that is vital to the health and the economy of the country. Despite that, and considering its vital importance, the impacts of groundwater are not widely understood.

The principal effect of irrigation from groundwater sources is connected to the potential for overuse. For obvious reasons, irrigation from groundwater is most likely to occur in arid regions where the opportunity for recharge from natural precipitation is small and where high demand is present.[111] As a result, withdrawals may not be balanced by recharge, and the groundwater levels can be lowered until they reach unsustainable depths.[112] In the United States, around 10 million acres of land are irrigated from groundwater sources in which pumping exceeds recharge and water tables are declining.[113] Often associated with

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101. John C. Keene, *Managing Agricultural Pollution*, 11 ECOLOGY L.Q. 135, 137 (1983). *See also* Robert W. Adler, *Water Quality and Agricultural: Assessing Alternative Futures*, 25 ENVIRONS ENVTL. L. & POL'Y J. 77, 78 (2002); James Stephen Carpenter, *Farm Chemicals, Soil Erosion, and Sustainable Agriculture*, 13 STAN. ENVTL. L.J. 190, 209-10 (1994); John H. Davidson, *Little Waters: The Relationship Between Water Pollution and Agricultural Drainage*, 17 ELR 10074 (Mar. 1987); J.B. Ruhl, *Farms, Their Environmental Harms, and Environmental Law*, 27 ECOLOGY L.Q. 263, 274-92 (2000); David Zaring, *Agriculture, Nonpoint Source Pollution, and Regulatory Control: The Clean Water Act's Bleak Present and Future*, 20 HARV. ENVTL. L. REV. 515, 516-21 (1996). The landmark article remains N. William Hines, *Agriculture: The Unseen Foe in the War on Pollution*, 55 CORNELL L. REV. 740 (1970).
102. Nat'l Research Council, *supra* note 17, at 3-4; Nat'l Research Council, *supra* note 22, at 10.
103. *Id.*
104. Nat'l Research Council, *supra* note 22, at 73.
105. *Water in the West*, *supra* note 49, at 2-30.
106. Nat'l Research Council, *supra* note 22, at 73.
107. *Id.*
108. John H. Davidson, *Factory Fields: Agricultural Practices, Polluted Water and Hypoxic Oceans*, 9 GREAT PLAINS NAT. RESOURCES J. 1 (2004).
109. *Id.*
110. JOB, GROUNDWATER ECONOMICS, *supra* note 10, at 38.
111. *Id.*
112. *Id.*
113. DESIGN, *supra* note 1, at 83.

regional declines in groundwater levels is subsidence as a result of a decline in the elevation of the land surface, a phenomenon that is particularly noticeable in California's Central Valley, parts of Arizona, central Florida, and the Texas Gulf Coast.

Groundwater is also typically connected to surface formations of springs, wetlands, and flowing streams and rivers. This connection is now viewed as one more essential stage in the hydrologic cycle that affects both the quantity and quality of supply in both sources.[114] Overuse by pumping of the underlying groundwater formations can, as a result, lower the levels and even eliminate these surface resources and the ecosystems associated with them.[115]

Water table decline along coastal areas may allow saltwater intrusion into groundwater aquifers.[116] When water table levels are reduced sufficiently, saltwater can move inland making the groundwater unfit for use.[117] This is a particularly difficult problem for coastal cities that overlie freshwater sources but which must limit use in order to avoid saltwater intrusion.

The most prominent environmental effect of groundwater pumping is the overuse of existing supply. However the principles of sustainable development may be applied in other contexts, with groundwater, the concern is with balancing current use with reliable annual recharge. To the extent that usage exceeds recharge, the groundwater source is being "mined." If the imbalance continues, the current usage cannot be sustained.

Regional and local examples of groundwater overuse are numerous. Perhaps, the most notable is the Ogallala Aquifer, which underlies the central plains states of South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas.[118] More than 90% of the water pumped from the Ogallala irrigates about one-fifth of all U.S. cropland, accounting for 30% of all groundwater used for irrigation in the United States.[119] The aquifer, however, is being depleted in many areas. Six percent of the aquifer has dropped to an unusable level that can no longer be pumped.[120] If irrigation continues to draw water from the aquifer at the same rate, about 6% of the aquifer will be used up in 25 years.[121]

The first effect of aquifer mining is the increased cost of pumping as wells must be annually deepened.[122] A second effect is that farmland is removed from production. One estimate is that 20% of irrigated land over the Ogallala has returned to dry land use due to groundwater mining.[123] Finally, of course, continued mining must mean that the rich supply of farm production that has been generated in the High Plains will eventually be lost. If predictions about a drying climate over the Ogallala hold, recharge will be reduced further.[124] The potential water scarcity suggested by the Ogallala example is a reminder that where irrigation from groundwater exceeds annual recharge, the supply of food now produced by irrigation must eventually be reduced. As a result, by overusing the aquifer today, we are creating an unsustainable level of food production.[125]

3. *Responding to Environmental Impacts: Law and Policy*

The system of riparianism in the East and prior appropriation in the West were developed as property doctrines, but during the second half of the last century statutory permit systems were laid over the traditional property rules.[126] As competition for water increased nationwide, administrative permit processes became the fora for considering the extent to which elements such as "reasonable use," "beneficial use," and "public

114. JOB, GROUNDWATER ECONOMICS, *supra* note 10, at 51.
115. *Id.*
116. DESIGN, *supra* note 1, at 84.
117. *Id.*
118. JOB, GROUNDWATER ECONOMICS, *supra* note 10, at 12.
119. *Id.*
120. *Id.*
121. *Id.*
122. *Id.*
123. *Id.*
124. *Id.*
125. *Id.*
126. SAX ET AL., *supra* note 2, at 12-15.

interest" would expand to accommodate increased municipal demand as well as wildlife and environmental concerns.[127]

As irrigation and population growth in the east increased demand, the eastern states inevitably began to draw on elements of prior appropriation, such as temporal priority and concerns over wasteful use. The western states, in turn, are drawing on aspects of riparianism, exemplified by concerns over protecting areas of origin from transbasin diversion schemes.

Over the last few decades, new themes have been introduced into water law and policy and are achieving various degrees of ascendency among the states.[128]

One theme is water as a public trust with water held by the state as custodian, charged with managing water in a manner that maximizes overall benefit to society.[129] A second and competing theme is water as an economic commodity, subject to full-cost pricing and trading in an open, private marketplace.[130] The third, and also competing theme, is that of water as a basic human right to which all people are entitled to access. Although these three themes appear to be incompatible, it may be that each has a role, depending upon circumstances.[131] As demand increases each of these themes will find voice as specific water contests are resolved.

C. Other Factors Affecting the Impact of Irrigation

1. *Shift to Large, Integrated Farm Operations*

The evolution of agriculture toward larger units of production is particularly evident in irrigated agriculture, where well-financed, integrated, and diversified farm operations are becoming normal.[132] A variety of factors favor this trend, including a decline in the overall farm population, a federal farm policy that favors large producers, and the ability of large producers to bear market risk.[133] Larger units are also better positioned to acquire and benefit from technology because irrigation is a capital-intensive enterprise most likely to benefit large farming entities with vast acreage available for farming.

2. *Conversion of Rangeland to Irrigation*

In recent years, a convergence of developments have led to a pattern of rapid conversion of native prairie grasslands to croplands and, in many cases, irrigated croplands. These lands are concentrated in the Dakotas, eastern Montana, Nebraska, and Kansas. Until recently, the best agricultural use of these rich native grasslands was assumed to be grazing; the topsoils are thin and the quality of the soils marginal, often sandy. The native grasses support a healthy grazing agriculture in association with a diverse ecosystem of wetlands, small rivers, and prairie. The advent of federal subsidies for ethanol production, the desire of landowners for access to federal crop benefits, new seeds suitable for marginal lands, and a steady reduction in the costs of technology have led to a rapid conversion to crops. The result is a spread of irrigation to lands that may not be well-suited to it, with the possibility of new regions of polluted runoff.[134]

3. *Conversion of Wetlands to Irrigated Farmland*

Irrigation can lead to the elimination of wetlands, playa lakes, prairie potholes, lakes, and flowing streams, all of which are vital to the survival of natural systems and wildlife of all kinds. Surface water and groundwater sources are typically connected—draw down one and you draw down the other. Surface wetlands and potholes are typically only the point where fully charged groundwater formations spill onto the sur-

127. *Id.*
128. *Id.*
129. *Id.* at 590-605.
130. *Id.* at 19.
131. *See* Barton H. Thompson Jr., *Water as a Public Community*, 95 Marq. L. Rev. 17 (2011).
132. Davidson, *supra* note 108, at 28-30.
133. Nat'l Research Council, *supra* note 22, at 173.
134. U.S. Government Accountability Office, *Farm Program Payments Are an Important Factor in Landowner's Decisions to Convert Grassland to Cropland* (Sept. 2007); *see also* Scott Stephens, *Plowing the Prairie*, Ducks Unlimited (July-Aug. 2005).

face. Thus, annual irrigation diversion from surface streams or pumping of underlying groundwater carries with it the likelihood that naturally occurring ecosystems will be depleted.

Irrigation is simply a more intense form of field agriculture. To farmers, any wetland, pothole, or minor wet slope is an impediment of efficient tillage.[135] Similarly, as the value of land and crops increases, the economic incentive to eliminate such "wet spots" increases as well. Irrigation is just one part of this dilemma. With increased demand for every use, surface water ecosystems are always the first to be placed at risk.[136]

As these surface water resources are depleted, the impact on aquatic species and migratory wildlife is direct and obvious.[137] Recurrent drought and flood are cycles to which aquatic species are adopted, but permanent elimination of the surface waters on which they depend means gradual elimination of the species themselves.

4. Climate Change and Variability

The example of the Ogallala Aquifer provides a useful discussion point for climate change and irrigation. In the case of the Ogallala, we can conclude that our farm production in the High Plains is artificially high because of overuse of the water supply and that production must necessarily decline in the future. Warming in the climate has the clear potential to impact water supplies, leading again to a reduction in farm production.[138]

The working example is the American West, which is not only the base of the nation's abundant irrigation production, but also the region that is being affected most by changed climate. As reported recently, "When compared to the 20th century average, the West has experienced an increase in average temperature during [2004-2007] that is 70 percent greater than the world as a whole."[139] The resulting decrease in snowpack, less snowfall, earlier snow melt, and reduced summer flow will not only disturb ecosystems and diminish reserves for municipal and industrial use, but will reduce agricultural production in all categories.[140] Thus, climate issues point to a conclusion that irrigation in the West may at some point be unsustainable.

D. Irrigation's Challenges and Opportunities

1. Reducing Polluted Return Flows

Treatment of polluted return flows is considered unlikely due to high cost as well as the need to develop disposal mechanisms for the high salt content waste byproduct.[141] Source control is sometimes accomplished by retiring land in which the salt load has become excessive and changing the cropping and use on the land.[142] Another approach is to alter the method of application from surface flow to spray or drip technologies. Recycling and diluting the water and the use of subsurface trickle technology can reduce the volume of drainage to under 10% of the amount of the water applied.[143] Each of these approaches is burdened, however, by high capital costs.

Polluted return flows may, perhaps, best be treated as land use problems, as is the case with so many of what we refer to as nonpoint sources. Although Congress has elected not to regulate nonpoint sources, it has correctly recognized that effective corrective measures will incorporate best-management practices (BMPs),[144] land use controls, and watershed management. BMPs recognize that national, or even regional, technology-based effluent standards cannot work a cure. Since nonpoint sources are the result of activities

135. *Id.*
136. *Id.*
137. *Id.*
138. It is clear that a warmer climate would accelerate the hydrologic cycle, increasing the rates of precipitation and evapotranspiration. *A New Era for Irrigation, supra* 22, at 74-75. Whether increased precipitation will occur at times and places necessary to support irrigation agriculture is the troubling question.
139. Rocky Mountain Climate Organization, *The West's Changed Climate* (Mar. 2008).
140. *Id.*
141. *Water in the West, supra* note 49, at 2-32.
142. *Id.*
143. *Id.*
144. 40 C.F.R. §§122.2, 130.2.

as various as human activity itself, controls must take the form of land management plans that consider the unique circumstances of any given plot of land.

Watershed management, like land use controls, has an inevitable role to play. Nonpoint sources are generated by human activity on the land but are often carried to watercourses by return flows from irrigation, precipitation, and diffused water. Nonpoint sources will be controlled not by any one landowner, but by a majority of landowners in a watershed who cooperate to implement a common plan.[145]

It is suggested that because so much of irrigation agriculture is organized in sophisticated irrigation districts—particularly in the West where the problem of polluted runoff is most evident—that the irrigation districts should be empowered to develop pollution-control plans suitable to their particular location and geology.[146]

2. *Water Conservation*

Whether the goal is to reduce return flows, increase water available for nonagricultural use, or increase overall food production, the real opportunity is for water conservation and more efficient use. Because agriculture in the West, the Great Plains, and Midwest developed prior to most other water uses of any scale, irrigators have had first call; they have been at the front of the line. From 1902 forward, new irrigation projects sponsored by the Bureau of Reclamation were not only numerous and vast in scale, they were also designed to serve irrigated agriculture first, with other uses servient and secondary.[147] The first effect of this was a tendency toward overuse, leading to waste and excessive runoff. In addition, these projects also integrated an enormous financial subsidy into irrigated agriculture, which eliminated any necessities for conservation and efficiency in water use.

In recent decades, the favored place at the front of the water use line that irrigation enjoyed for so long has been challenged as the West's great new cities and industry seek water, recreation grows as a major economic use, and the public calls for ecosystem protections. A new era is underway in which a balance among water use, water pricing, and ecosystems is sought.[148]

The heavy subsidies for irrigation waters from Bureau of Reclamation projects insulated users from water markets, which in the absence of Bureau programs would have increased the value of the water.[149] The gradual emergence of water markets offers an attractive mechanism for achieving efficiency in water use by applying high-value water to high-value crops while providing nonagricultural users the opportunity to acquire supplies at the higher cost.[150] Markets should also serve to increase the incentives for conservation. By raising the value of water, markets might also decrease unnecessary agricultural runoff and resulting sources of pollution.

Conclusion

Irrigation will play a pivotal role as agriculture responds to the many challenges outlined in this chapter. Done well, it will be a larger part of the solution. If it continues in the old ways, it will present a serious drag on innovation.

Irrigation has historically enjoyed first call on water resources, leading to overuse. Today, that water is sought by urban, industrial, recreational, and environmental users, while the overall supply in key regions is facing potential reduction as the result of global warming and climate change. While it strives to increase production of essential foods, irrigation agriculture is challenged to do so with less water and while reducing the pollution that is part of field runoff. In early stages, this may be achieved by moving from lower-value, water-consumptive crops to high-value, water-conserving crops. Subsequent stages will require stronger measures, ranging from water-saving technologies to abandonment of irrigated agriculture in water-scarce regions such as the High Plains.

145. *Water in the West*, *supra* note 49, at 6-21.
146. *See* John H. Davidson, *Using Special Water Districts to Control Nonpoint Sources of Water Pollution*, 65 CHI-KENT L. REV. 503 (1990).
147. MACDONNELL, *supra* note 14, at 1-9.
148. *Id.*
149. *Id.*
150. *Id.*

In the larger sense, the issue is that of increased reliance on an ever more finite natural resource. In this, it is hardly distinguishable from other examples such as ocean fisheries, prime farmland, and forests. Is it possible to absorb increased competition for a limited resource while establishing a sustainable level of food production and providing for survival of some portion of water-dependent ecosystems? A positive answer will involve institutional, technological, and social change to a degree that is not yet in sight.